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RADIAL VELOCITIES OF 99 STARS OF THE SECOND AND THIRD SPECTRAL CLASSES OBSERVED AT BONN

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During the years 1903 to 1907 I have, in collaboration with Dr. W. Zurhellen, obtained spectrograms of nearly all stars of the second and third spectral classes down to the fourth visual, or fifth photographic magnitude, which could be observed in Bonn, using the photographic refractor by Repsold and Steinheil of aperture 30 cm, and focal-length 5.1 m. The radial velocities resulting from provisional computations are briefly communicated herewith. The definitive results will be published later *in extenso* in the *Veröffentlichungen der Bonner Sternwarte*, but they will not differ much from the values given here.

The spectrograph employed was constructed by Töpfer of Potsdam, and has three 60° prisms of heavy Jena flint, which are set at the minimum of deviation for $H\gamma$. The height of the prisms is 32 mm, and the lengths of their sides are 52, 54, and 56 mm. The collimating lens is of 28 mm aperture and 450 mm focal-length, and the camera lens of 30 mm aperture and 361 mm focal-length. The spectrum is sharply defined from λ 4150 to λ 4500. At medium temperature the dispersion is as follows:

λ	Dispersion for One Tenth-Meter	Tenth-Meters per mm
4200	46″.2 = 0.081 mm	12.4
4300	39.8 0.070	14.4
$H\gamma$	37.6 0.066	15.2
4400	34.6 0.061	16.5
4500	30.6 0.054	18.7

The spectrograph is automatically kept at constant temperature by electric means. The light of the iron arc has served for comparison after being diffusely projected through a ground-glass disk upon the slit. From two to five exposures of the comparison spectrum are made, according to the length of the exposure on the star.

A microscope by Töpfer, the screw of which has a pitch of $\frac{1}{4}$ mm, has served for the measurement of the spectrograms. The spectrograms of the first year, 1903, were measured both by myself and by Zurhellen, and my measurements are distinguished in the following list by a * attached to the plate number. The results of the two observers may be regarded as practically independent, inasmuch as we intentionally observed lines as different as possible. I have already published in detail these measurements in 1903, in *Astronomische Nachrichten*, Nos. 3972–73 (**166**, 177, 1904); the results must be briefly repeated, however, in connection with the subsequent measures. The spectrograms of the years 1904 to 1907 were all measured by Mr. Zurhellen alone, who has carried out this arduous work with great care. All the measures were in every case made in both positions of the plate, with red to right and red to left, and the mean was used in the computations. The wave-lengths of the *Fe* lines, as a rule extending from λ 4210 to λ 4482, were taken from Kayser, the wave-lengths of the stellar lines, from λ 4220 to 4475, from Rowland.

The following tabulation of the resulting radial velocities requires little explanation. Below the name of the star is given the right ascension and declination for 1900, the spectral type according to Miss Maury (*Harvard Annals*, **28**) and the photographic magnitude according to the *Draper Catalogue* (*Harvard Annals*, **27**). The column "Exposure" gives the duration in minutes, in parentheses when there was interference by clouds, and the initial of the observer, K or Z; in taking some plates the observers exchanged places, which is indicated by KZ. The column "Red. to ☉" contains the sum of the annual and daily components of the velocity of the earth, the first being computed by Schlesinger's table in the *Astrophysical Journal* (**10**, 1, 1899). The last two columns contain the number m of the star lines measured and the average deviation $\frac{1}{m}\Sigma v$ of the separate lines from the mean for the plate.

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\Sigma v$

δ Andromedae

α 0ʰ 34ᵐ.0, δ +30° 19′ Type XV, Mag. 4.79

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\Sigma v$
		min.		km	km	km		km
492	1905, Oct. 20.424	(110) Z	0ʰ 1ᵐ	+ 1.48	− 3.45	− 1.97	16	±1.9
777	1906, Oct. 8.495	105 Z	+0 52	− 5.75	+ 2.20	− 3.55	17	3.3
793	1906, Nov. 10.433	120 Z	+1 34	+ 9.81	−12.92	− 3.11	14	1.8
1009	1907, Nov. 1.451	120 Z	+1 24	+ 3.32	− 8.85	− 5.53	20	1.7

Mean: − 3.54

α Cassiopeiae

α 0ʰ 34ᵐ.8, δ +56° 0′ Type XV, Mag. 3.88

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\Sigma v$
278	1904, Oct. 19.416	51 K	−0 15	− 5.73	+ 3.38	− 2.35	16	±1.7
281	1904, Oct. 27.430	53 K	+0 36	− 2.43	+ 0.52	− 1.91	15	1.4
510	1905, Nov. 30.303	62 K	−0 15	+ 7.91	−10.97	− 3.06	20	2.1
820	1906, Dec. 23.221	60 K	−0 43	+14.43	−16.92	− 2.49	25	1.7

Mean: − 2.45

β Ceti

α 0ʰ 38ᵐ.5, δ −18° 32′ Type XV, Mag. 3.86

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\Sigma v$
311	1905, Jan. 1.238	60 K	+0 16	+42.33	−27.93	+14.40	16	±1.8
313	1905, Jan. 2.230	60 K	+0 8	+43.01	−27.84	+15.17	15	1.6
525	1905, Dec. 18.285	70 K	+0 26	+43.27	−28.22	+15.05	16	1.3
1031	1907, Nov. 21.350	85 K	+0 12	+38.60	−23.85	+14.75	17	1.9

Mean: +14.84

η Cassiopeiae

α 0ʰ 43ᵐ.0, δ +57° 17′ Type XIII, Mag. 4.73

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\Sigma v$
751	1906, Aug. 29.545	105 Z	−0 42	− 7.40	+17.83	+10.43	25	±2.0
802	1906, Nov. 23.297	112 Z	−1 00	+18.88	− 7.75	+11.13	25	2.8
808	1906, Dec. 18.241	100 Z	−0 42	+23.38	−15.11	+ 8.27	19	2.7
1008	1907, Nov. 1.364	100 Z	−0 51	+ 9.71	− 0.04	+ 9.67	20	1.4

Mean: + 9.88

β Andromedae

α 1ʰ 4ᵐ.1, δ +35° 5′ Type XVII, Mag. 4.57

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\Sigma v$
537	1905, Dec. 31.261	80 K	+0 18	+27.31	−25.65	+ 1.66	29	±2.1
540	1906, Jan. 1.260	90 K	+0 21	+27.22	−25.81	+ 1.41	26	2.5
821	1906, Dec. 23.311	90 K	+0 58	+25.25	−24.12	+ 1.13	19	2.4
1016	1907, Nov. 4.443	100 Z	+0 54	+ 7.91	− 6.17	+ 1.74	20	2.3

Mean: + 1.49

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	$1/m\Sigma v$
	α Ursae minoris							
	α 1^h 22^m.6, δ +88° 46′			Type XIII, Mag. bright				
		min.		km	km	km		km
104*	1903, July 2.371	60 K	− 9^{h}20^m	−17.45	+ 2.57	−14.88	16	±1.6
104	1903, July 2.371	60 K	− 9 20	−16.13	+ 2.57	−13.56	18	2.4
106*	1903, July 4.470	79 K	− 6 50	−18.70	+ 2.99	−15.71	17	2.3
106	1903, July 4.470	79 K	− 6 50	−19.51	+ 2.99	−16.52	17	1.8
408	1905, May 30.361	50 K	−11 43	− 7.77	− 3.88	−11.65	16	2.0
410	1905, May 31.369	25 K	−11 27	−11.43	− 3.69	−15.12	14	2.7
414	1905, June 19.371	40 K	−10 10	−13.41	+ 0.08	−13.33	16	2.5
						Velocity variable		
	η Piscium							
	α 1^h 26^m.1, δ +14° 50′			Type XIV, Mag. 5.02				
293	1904, Nov. 15.398	122 Z	+0 13	+28.67	−14.24	+14.43	14	±1.5
505	1905, Nov. 27.383	(100)Z	+0 37	+34.04	−19.38	+14.66	17	1.8
837	1907, Jan. 24.261	100 Z	+1 30	+45.66	−29.93	+15.73	18	1.9
1033	1907, Nov. 22.435	108 Z	+1 31	+31.41	−17.14	+14.27	16	1.7
					Mean:	+14.77		
	υ Persei							
	α 1^h 31^m.8, δ +48° 7′			Type XV, Mag. 5.10				
515	1905, Dec. 1.422	100 Z	+1 44	+29.12	−11.81	+17.31	16	±3.0
830	1907, Jan. 23.253	100 Z	+1 9	+42.68	−24.41	+18.27	19	2.6
839	1907, Jan. 26.245	100 Z	+1 9	+43.05	−24.56	+18.49	25	1.9
1036	1907, Dec. 4.306	105 Z	−0 54	+31.21	−12.56	+18.65	16	1.7
					Mean:	+18.18		
	γ Andromedae, maj. dpl.							
	α 1^h 57^m.8, δ +41° 51′			Type XV, Mag. 4.05				
290	1904, Nov. 14.448	53 K	+0 49	− 5.19	− 4.67	− 9.86	16	±1.4
320	1905, Jan. 8.340	50 K	+1 51	+13.50	−24.35	−10.85	15	1.4
557	1906, Jan. 17.272	65 K	+0 47	+15.69	−25.71	−10.02	16	2.6
1020	1907, Nov. 5.464	75 Z	+0 34	−10.82	− 0.16	−10.98	20	1.7
					Mean:	−10.43		
	α Arietis							
	α 2^h 1^m.5, δ +23° 0′			Type XV, Mag. 4.13				
259	1904, Aug. 25.601	40 Z	−0 52	−38.37	+25.94	−12.43	20	±2.0
295	1904, Nov. 16.382	51 Z	−0 42	− 2.21	− 9.35	−11.56	20	1.9
299	1904, Dec. 21.325	45 K	+0 14	+10.68	−23.95	−13.27	20	1.8
314	1905, Jan. 2.283	40 K	0 0	+12.75	−27.11	−14.36	20	1.5
507	1905, Nov. 28.374	50 Z	−0 6	+ 2.70	−14.94	−12.24	20	2.0
558	1906, Jan. 22.224	50 K	−0 6	+16.66	−29.66	−13.00	20	1.9
					Mean:	−12.81		

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\,\Sigma v$

ξ' Ceti

α 2h 7m.7, δ +8° 23′ Type XIV ?, Mag. 5.09

		min.		km	km	km		km
526	1905, Dec. 18.369	120 Z	+0h59m	+23.74	−24.44	− 0.70	14	±3.3
824	1907, Jan. 22.264	120 Z	+0 44	+22.46	−30.20	− 7.74	23	3.0
843	1907, Jan. 29.251	120 Z	+0 53	+20.60	−30.05	− 9.45	17	2.1
1037	1907, Dec. 16.405	120 Z	+1 41	+15.27	−23.65	− 8.38	16	1.8

Velocity variable

o Ceti, dark lines

α 2h 14m.3, δ −3° 26′ Type XX, Mag. var.

804	1906, Dec. 7.377	100 Z	+0 20	+87.14	−20.60	+66.54	16	±3.9
810	1906, Dec. 18.351	90 KZ	+0 26	+92.25	−24.16	+68.09	13	4.9
818	1906, Dec. 22.354	100 KZ	+0 46	+89.06	−25.27	+63.79	14	3.4

Mean: +66.14

o Ceti, Hγ bright line

804	1906, Dec. 7.377	100 Z	+0 20	+71.10	−20.60	+50.50	1	
807	1906, Dec. 12.356	(40) Z	+0 9	+75.00	−22.30	+52.70	1	
809	1906, Dec. 18.305	20 K	−0 40	+73.95	−24.06	+49.89	1	
810	1906, Dec. 18.351	90 KZ	+0 26	+76.93	−24.16	+52.77	1	
813	1906, Dec. 21.302	16 K	−0 33	+75.40	−24.90	+50.50	1	
817	1906, Dec. 22.310	17 K	−0 18	+72.85	−25.18	+47.67	1	
818	1906, Dec. 22.354	100 KZ	+0 46	+76.97	−25.27	+51.70	1	
822	1906, Dec. 23.362	12 K	+1 2	+74.20	−25.55	+48.65	1	

Mean of 4 long expos.: +51.92
Mean of 4 short expos.: +49.18

α Ceti

α 2h 57m.1, δ +3° 42′ Type XVII, Mag. 4.63

300	1904, Dec. 21.396	100 Z	+1 1	− 2.37	−21.61	−23.98	10	±2.0
528	1905, Dec. 25.383	100 K	+0 57	− 0.71	−22.89	−23.60	14	2.1
555	1906, Jan. 16.292	120 KZ	+0 13	+ 5.89	−28.18	−22.29	17	3.1
852	1907, Feb. 5.247	100 Z	+0 26	+ 5.57	−29.46	−23.89	12	2.2

Mean: −23.44

γ Persei

α 2h 57m.5, δ +53° 7′ Type XIV, Mag. 4.01

527	1905, Dec. 18.463	70 K	+2 23	+14.77	−11.78	+ 2.99	17	±2.5
567	1906, Jan. 23.292	80 K	+0 40	+23.76	−22.39	+ 1.37	18	3.2
831	1907, Jan. 23.341	75 K	+1 50	+22.83	−22.40	+ 0.43	13	1.6
853	1907, Feb. 7.255	70 K	+0 44	+25.89	−24.39	+ 1.50	19	2.4

Mean: + 1.57

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\ \Sigma v$
			κ Persei					
	$\alpha\ 3^h\ 2^m.7$, $\delta+44°\ 29'$			Type XV, Mag. 5.12				
		min.		km	km	km		km
328	1905, Jan 14.333	120 Z	$+0^h59^m$	+53.38	−22.99	+30.39	16	±1.4
529	1905, Dec. 26.397	115 K	+1 16	+47.24	−16.92	+30.32	17	2.8
823	1907, Jan. 13.370	(120)Z	+1 47	+53.73	−22.63	+31.10	22	1.6
					Mean:	+30.60		
			α Persei					
	$\alpha\ 3^h\ 17^m.2$, $\delta+49°\ 30'$			Type XII*ac*, Mag. bright				
264	1904, Aug. 29.639	21 Z	−0 58	−27.55	+25.40	− 2.15	20	±2.2
270	1904, Sept. 11.680	25 Z	+0 53	−26.08	+24.14	− 1.94	20	2.5
291	1904, Nov. 14.488	27 K	+0.29	− 6.74	+ 3.53	− 3.21	19	2.4
303	1904, Dec. 22.358	25 K	−0 10	+11.92	−13.09	− 1.17	20	2.6
559	1906, Jan. 22.271	25 K	−0 13	+21.04	−22.81	− 1.77	20	2.2
600	1906, Mar. 7.239	27 K	+1 54	+21.97	−25.18	− 3.21	20	2.6
					Mean:	− 2.24		
			f Tauri					
	$\alpha\ 3^h\ 25^m.4$, $\delta+12°\ 36'$			Type XV ?, Mag. 5.11				
331	1905, Jan. 15.357	120 KZ	+1 15	+53.43	−26.80	+26.63	15	±1.6
842	1907, Jan. 27.307	(100)KZ	+0 50	+45.32	−28.96	+16.36	17	2.6
847	1907, Feb. 1.300	120 Z	+0 59	+45.40	−29.56	+15.84	16	3.1
						Velocity variable		
			γ Tauri					
	$\alpha\ 4^h\ 14^m.1$, $\delta+15°\ 23'$			Type XIV ?, Mag. 4.85				
854	1907, Feb. 7.327	102 Z	+1 11	+67.61	−28.76	+38.85	20	±3.0
857	1907, Feb. 9.282	100 Z	+0 15	+69.87	−28.98	+40.89	16	2.0
867	1907, Mar. 2.298	108 Z	+2 1	+68.98	−29.86	+39.12	18	2.4
					Mean:	+39.62		
			δ Tauri					
	$\alpha\ 4^h\ 17^m.2$, $\delta+17°\ 18'$			Type XV, Mag. 5.00				
346	1905, Jan. 26.376	105 Z	+1 34	+70.26	−26.31	+43.95	17	±2.0
815	1906, Dec. 21.460	120 Z	+1 11	+52.60	−12.28	+40.32	14	2.2
825	1907, Jan. 22.369	120 KZ	+1 6	+63.02	−25.03	+37.99	29	2.2
						Velocity variable ?		
			ε Tauri					
	$\alpha\ 4^h\ 22^m.8$, $\delta+18°\ 58'$			Type XV ?, Mag. 4.83				
344	1905, Jan. 23.381	115 Z	+1 24	+65.28	−25.06	+40.22	16	±1.2
572	1906, Jan. 24.355	115 Z	+0 49	+63.01	−25.23	+37.78	21	2.1
819	1906, Dec. 22.447	120 Z	+0 51	+52.22	−11.98	+40.24	19	2.2
					Mean:	+39.41		

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	1/m Σv
				α Tauri				
	α $4^h\ 30^m\!.2$, δ + 16° 19′			Type XVI, Mag. 3.94				
		min.		km	km	km		km
312	1905, Jan. 1.352	50 K	$-0^h 52^m$	+72.34	−16.06	+56.28	15	±1.9
315	1905, Jan. 2.366	38 K	−0 27	+73.12	−16.53	+56.59	15	1.6
321	1905, Jan. 8.392	40 K	+0 34	+75.88	−19.17	+56.71	15	1.5
354	1905, Feb. 9.311	50 K	+0 43	+84.35	−28.49	+55.86	15	2.3
481	1905, Sept. 22.698	47 Z	+0 48	+28.86	+27.33	+56.19	20	1.9
516	1905, Dec. 1.501	50 Z	+0 39	+55.57	− 0.68	+54.89	20	1.9
769	1906, Sept. 24.691	57 Z	+0 44	+28.98	+27.01	+55.99	20	1.9
					Mean:	+56.07		
				π3 Orionis				
	α $4^h\ 44^m\!.3$, δ + 6° 47′			Type XIII*a*, Mag. 4.05				
334	1905, Jan. 20.370	90 Z	+0 35	+47.60	−22.15	+25.45	14	±2.2
561	1906, Jan. 22.412	80 K	+1 42	+49.90	−22.80	+27.10	16	3.5
811	1906, Dec. 18.457	100 Z	+0 29	+33.75	− 7.98	+25.77	12	2.9
					Mean:	+26.11		
				ι Aurigae				
	α $4^h\ 50^m\!.4$, δ + 33° 0′			Type XV, Mag. 4.87				
339	1905, Jan. 22.384	100 Z	+0 57	+40.72	−21.67	+19.05	13	±1.9
523	1905, Dec. 17.441	100 Z	−0 4	+24.61	− 5.32	+19.29	17	2.4
844	1907, Jan. 29.350	(90)KZ	+0 34	+43.46	−23.78	+19.68	22	1.8
					Mean:	+19.34		
				ν Aurigae				
	α $5^h\ 44^m\!.6$, δ + 39° 7′			Type XVI ?, Mag. 5.17				
351	1905, Feb. 8.378	120 Z	+1 1	+34.57	−22.92	+11.65	13	±2.4
576	1906, Feb. 5.392	120 Z	+1 8	+31.59	−21.89	+ 9.70	15	1.9
871	1907, Mar. 3.335	120 Z	+1 28	+39.16	−27.91	+11.25	18	2.2
					Mean:	+10.87		
				α Orionis				
	α $5^h\ 49^m\!.8$, δ + 7° 23′			Type XVIII, Mag. bright				
356	1905, Feb. 9.407	60 Z	+1 41	+51.00	−23.11	+27.89	10	±2.8
367	1905, Mar. 1.309	62 Z	+0 39	+52.84	−27.54	+25.30	11	2.5
533	1905, Dec. 30.474	80 K	+1 35	+32.24	− 5.78	+26.46	18	2.7
591	1906, Mar. 4.317	60 Z	+1 1	+54.58	−27.94	+26.64	15	2.1
					Mean:	+26.57		
				δ Aurigae				
	α $5^h\ 51^m\!.3$, δ + 54° 17′			Type XV, Mag. 4.81				
874	1907, Mar. 4.323	95 Z	+1 8	+35.96	−24.78	+11.18	19	±1.6
882	1907, Mar. 7.307	90 Z	+0 57	+36.57	−25.09	+11.48	17	2.4
892	1907, Mar. 21.293	(88)KZ	+1 32	+35.85	−25.72	+10.13	23	1.7
					Mean:	+10.93		

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\,\Sigma v$

μ Geminorum

α 6h 16m.9, $\delta + 22° 34'$ Type XVIII, Mag. 4.85

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\,\Sigma v$
		min.		km	km	km		km
530	1905, Dec. 26.503	100 K	+0h 35m	+57.99	− 0.42	+57.57	14	±2.5
573	1906, Jan. 24.447	100 Z	+1 8	+72.16	−15.06	+57.10	14	2.7
826	1907, Jan. 22.471	120 Z	+1 33	+70.40	−14.07	+56.33	16	2.8

Mean: +57.00

ε Geminorum

α 6h 37m.8, $\delta + 25° 14'$ Type XIV, Mag. 4.66

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\,\Sigma v$
370	1905, Mar. 8.366	90 Z	+1 40	+39.08	−27.90	+11.18:	11	±2.1
379	1905, Mar. 22.310	(130)KZ	+1 15	+38.15	−29.63	+ 8.52	15	1.5
588	1906, Feb. 28.376	(110)Z	+1 23	+34.86	−26.06	+ 8.80	18	2.5
833	1907, Jan. 23.468	105 Z	+1 12	+21.20	−12.29	+ 8.91	22	1.8

Mean: + 9.35

α Canis minoris

α 7h 34m.1, $\delta + 5° 29'$ Type XII*a*, Mag. bright

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\,\Sigma v$
347	1905, Jan. 26.442	10 K	−0 7	+ 1.07	− 5.77	− 4.70	15	±0.8
359	1905, Feb. 13.352	(32)K	−1 6	+11.09	−14.13	− 3.04	14	1.8
381	1905, Apr. 13.294	18 K	+1 22	+25.27	−28.60	− 3.33	20	1.5
497	1905, Nov. 3.740	18 Z	+1 31	−31.76	+27.42	− 4.34	20	1.5
534	1905, Dec. 30.522	16 K	0 0	−11.15	+ 7.90	− 3.25	20	1.9
627	1906, Mar. 28.292	14 K	+0 16	+23.76	−27.23	− 3.47	20	2.1
794	1906, Nov. 10.684	20 Z	+0 35	−29.53	+26.34	− 3.19	20	1.4

Mean: − 3.62

κ Geminorum

α 7h 38m.4, $\delta + 24° 38'$ Type XIV, Mag. 4.62

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\,\Sigma v$
372	1905, Mar. 13.421	115 Z	+2 19	+48.44	−25.90	+22.54	14	±2.1
375	1905, Mar. 20.373	120 Z	+1 36	+49.58	−27.44	+22.14	16	1.8
602	1906, Mar. 7.363	120 Z	+0 31	+45.15	−24.00	+21.15	19	2.8
883	1907, Mar. 7.387	90 KZ	+1 5	+44.85	−23.96	+20.89	22	2.6

Mean: +21.68

β Geminorum

α 7h 39m.2, $\delta + 28° 16'$ Type XV, Mag. bright

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\,\Sigma v$
130	1904, Apr. 15.367	30 K	+3 11	+35.06	−29.61	+ 5.45	14	±1.5
287	1904, Oct. 30.687	(47)Z	−0 6	−24.81	+28.61	+ 3.80	15	1.3
368	1905, Mar 1.408	36 Z	+1 12	+26.16	−22.22	+ 3.94	16	1.1
368[1]	1905, Mar. 1.408	36 Z	+1 12	+26.49	−22.22	+ 4.27	20	1.4
382	1905, Apr. 13.330	39 K	+2 9	+33.42	−29.62	+ 3.80	20	1.9
385	1905, Apr. 14.323	42 K	+2 3	+34.66	−29.60	+ 5.06	20	1.7
494	1905, Nov. 3.668	34 Z	−0 18	−22.81	+28.04	+ 5.23	20	1.2
563	1906, Jan 22.501	30 K	+0 55	+10.90	− 5.20	+ 5.70	20	1.2
563[1]	1906, Jan. 22.501	30 K	+0 55	+10.46	− 5.20	+ 5.26	20	1.8
909	1907, Mar. 28.301	40 K	+0 23	+33.85	−28.49	+ 5.36	20	2.0

Mean: + 4.79

[1] Second measure with partially different lines.

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	1/m Σv

β Cancri

$\alpha\ 8^{h}\ 11^{m}.1$, $\delta + 9^\circ\ 30'$ Type XV, Mag. 5.06

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	1/m Σv
		min.		km	km	km		km
634	1906, Apr. 2.325	120 KZ	$+0^{h}46^{m}$	+51.95	−27.26	+24.69	12	±3.0
897	1907, Mar. 24.328	125 KZ	+0 14	+51.20	−25.23	+25.97	13	2.5
914	1907, Mar. 29.357	140 KZ	+1 15	+51.67	−26.47	+25.20	15	2.9

Mean: +25.29

o Ursae majoris

$\alpha\ 8^{h}\ 22^{m}.0$, $\delta + 61^\circ\ 3'$ Type XIV, Mag. 4.66

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	1/m Σv
855	1907, Feb. 7.418	90 KZ	−0 45	+29.81	− 9.97	+19.84	23	±2.6
860	1907, Feb. 9.407	100 KZ	−0 53	+31.61	−10.68	+20.93	16	2.6
886	1907, Mar. 9.312	(35) Z	−1 20	+40.52	−18.81	+21.71	16	2.8
900	1907, Mar. 26.306	80 KZ	−0 21	+42.45	−21.69	+20.76	28	2.4

Mean: +20.81

ι Cancri

$\alpha\ 8^{h}\ 40^{m}.6$, $\delta + 29^\circ\ 7'$ Type XIV, Mag. 4.85

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	1/m Σv
584	1906, Feb. 15.495	110 Z	+1 20	+28.74	−10.57	+18.17	14	±1.7
894	1907, Mar. 22.408	120 Z	+1 31	+40.61	−24.19	+16.42	13	2.1
910	1907, Mar. 28.369	120 Z	+0 59	+41.89	−25.72	+16.17	14	2.7
918	1907, Mar. 30.365	140 Z	+1 1	+43.74	−26.18	+17.56	14	2.4

Mean: +17.08

ζ Hydrae

$\alpha\ 8^{h}\ 50^{m}.1$, $\delta + 6^\circ\ 19'$ Type XV, Mag. 4.42

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	1/m Σv
365	1905, Feb. 28.425	(65)Z	+0 22	+37.29	−12.78	+24.51	16	±4.0
638	1906, Apr. 3.333	90 KZ	+0 23	+49.43	−25.05	+24.38	25	2.4
875	1907, Mar. 4.460	90 Z	+1 27	+38.03	−14.44	+23.59	20	2.2

Mean: +24.16

40 *Lyncis*

$\alpha\ 9^{h}\ 15^{m}.0$, $\delta + 34^\circ\ 49'$ Type XVI, Mag. 4.98

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	1/m Σv
613	1906, Mar. 17.435	120 Z	+1 17	+60.66	−20.18	+40.48	10	±4.3
639	1906, Apr. 3.412	120 Z	+1 52	+64.17	−25.04	+39.13	19	2.2
898	1907, Mar. 24.425	120 KZ	+1 30	+62.60	−22.36	+40.24	15	2.7
942	1907, Apr. 24.354	120 Z	+1 50	+65.56	−27.99	+37.57	19	2.4

Mean: +39.35

α Hydrae

$\alpha\ 9^{h}\ 22^{m}.7$, $\delta - 8^\circ\ 13'$ Type XV, Mag. 4.16

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	1/m Σv
136	1904, Apr. 20.342	66 K	+1 12	+21.95	−24.58	− 2.63	14	±1.8
608	1906, Mar. 14.436	90 Z	+0 59	+ 9.03	−12.45	− 3.42	22	2.6
621	1906, Mar. 26.377	90 Z	+0 21	+15.02	−17.15	− 2.13	23	2.2
901	1907, Mar. 26.380	80 K	+0 24	+15.18	−17.06	− 1.88	16	2.2

Mean: − 2.51

θ Ursae majoris

α 9h 26m.2, δ +52° 8′ Type XIIIa, Mag. 4.14

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	$1/m\,\Sigma v$
		min.		km	km	km		km
376	1905, Mar. 20.466	60 Z	+2h 4m	+35.46	−19.61	+15.85	15	±1.9
383	1905, Apr. 13.408	88 Z	+2 14	+39.97	−23.74	+16.23	13	2.1
603	1906, Mar. 7.452	92 Z	+0 51	+30.25	−15.72	+14.53	18	2.4
926	1907, Apr. 1.381	75 K	+0 47	+39.01	−21.99	+17.02	16	1.8

Mean: +15.91

ε Leonis

α 9h 40m.2, δ +24° 14′ Type XIV *P*, Mag. 4.34

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	$1/m\,\Sigma v$
73*	1903, May 24.379	78 K	+3 59	+34.01	−28.50	+ 5.51	15	±2.8
73	1903, May 24.379	78 K	+3 59	+34.02	−28.50	+ 5.52	15	2.8
141	1904, Apr. 24.399	80 K	+2 32	+35.05	−28.19	+ 6.86	15	1.6
395	1905, Apr. 25.379	72 K	+2 7	+33.76	−28.26	+ 5.50	22	2.0
402	1905, May 15.349	(80)K	+2 41	+35.20	−29.11	+ 6.09	15	1.8

Mean: + 5.90

γ Leonis, maj. dpl.

α 10h 14m.5, δ +20° 21′ Type XV, Mag. 3.72

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	$1/m\,\Sigma v$
54*	1903, May 4.421	60 K	+3 6	− 7.22	−28.25	−35.47	13	±2.6
54	1903, May 4.421	60 K	+3 6	− 6.58	−28.25	−34.83	15	2.6
148	1904, May 9.415	68 K	+3 20	− 4.88	−28.87	−33.75	15	1.8
397	1905, May 3.349	60 Z	+1 21	− 6.59	−28.07	−34.66	15	1.0
929	1907, Apr. 2.422	70 K	+1 2	−15.15	−20.04	−35.19	30	2.1
948	1907, May 11.344	75 K	+1 43	− 5.81	−28.88	−34.69	20	2.3

Mean: −34.77

μ Ursae majoris

α 10h 16m.4, δ +42° 0′ Type XVI, Mag. 4.88

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	$1/m\,\Sigma v$
137	1904, Apr. 20.451	118 Z	+2 54	+11.99	−24.43	−12.44	15	±1.6
155	1904, May 16.376	90 KZ	+2 50	+16.39	−25.79	− 9.40	14	1.7
679	1906, May 3.377	(120)Z	+1 57	+11.46	−25.65	−14.19	14	3.0
680	1906, May 8.359	100 Z	+1 51	+10.95	−25.84	−14.89	13	3.4
681	1906, May 11.358	(120)Z	+2 1	+ 7.27:	−25.87	−18.60:	9	4.4

Velocity variable

46 *Leonis minoris*

α 10h 47m.7, δ +34° 45′ Type XV, Mag. 4.95

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	$1/m\,\Sigma v$
635	1906, Apr. 2.425	120 KZ	+0 33	+36.99	−18.02	+18.97	18	±3.2
906	1907, Mar. 27.477	120 Z	+1 23	+32.90	−15.84	+17.06	21	1.9
915	1907, Mar. 29.471	135 Z	+1 22	+34.76	−16.57	+18.19	21	2.0
940	1907, Apr. 22.378	120 Z	+0 43	+41.16	−23.54	+17.62	22	2.4

Mean: +17.96

α Ursae majoris

α 10ʰ 57ᵐ6, δ +62° 18′ Type XV, Mag. 4.10

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\,\Sigma v^2$
		min.		km	km	km		km
95*	1903, June 27.391	60 K	$+5^h 12^m$	+ 4.93	−12.03	− 7.10	13	±1.4
95	1903, June 27.391	60K	+5 12	+ 4.65	−12.03	− 7.38	15	1.6
135	1904, Apr. 19.458	45 KZ	+2 20	+ 9.27	−18.57	− 9.30	15	2.9
158	1904, May 19.356	37 K	+1 51	+10.43	−18.53	− 8.10	16	2.0
399	1905, May 11.376	60 Z	+1 47	+13.04	−19.02	− 5.98	16	1.3
670	1906, Apr. 13.413	60 K	+0 49	+11.48	−17.87	− 6.39	17	2.0

Mean: − 7.38

ψ Ursae majoris

α 11ʰ 4ᵐ0, δ +45° 3′ Type XV, Mag. 4.59

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\,\Sigma v^2$
131	1904, Apr. 15.501	105 KZ	+3 1	+18.63	−20.42	− 1.79	15	±1.9
146	1904, May 7.420	70 K	+2 30	+20.59	−23.65	− 3.06	15	1.5
401	1905, May 12.374	(110)Z	+1 42	+21.80	−23.89	− 2.09	15	2.4
649	1906, Apr. 6.471	110 Z	+1 40	+15.39	−18.01	− 2.62	22	3.0

Mean: − 2.39

ν Ursae majoris

α 11ʰ 13ᵐ1, δ +33° 38′ Type XVI ?, Mag. 5.15

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\,\Sigma v^2$
160	1904, May 20.389	124 KZ	+2 27	+18.35	−26.37	− 8.02	11	±1.8
163	1904, June 4.382	105 KZ	+3 16	+19.92	−26.24	− 6.32	14	2.0
938	1907, Apr. 10.467	120 Z	+1 40	+11.86	−18.50	− 6.64	13	1.9
946	1907, May 10.364	120 Z	+1 10	+16.47	−25.36	− 8.89	18	2.8

Mean: − 7.47

χ Ursae majoris

α 11ʰ 40ᵐ8, δ +48° 20′ Type XV, Mag. 4.92

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\,\Sigma v^2$
156	1904, May 16.474	114 KZ	+3 46	+16.29	−22.00	− 5.71	15	±3.3
159	1904, May 19.449	106 Z	+3 22	+14.05	−22.09	− 8.04	13	2.4
687	1906, May 29.381	105 Z	+2 22	+13.69	−22.02	− 8.33	15	3.1

Mean: − 7.36

β Virginis

α 11ʰ 45ᵐ5, δ + 2° 20′ Type XIII*a*, Mag. 4.40

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\,\Sigma v^2$
622	1906, Mar. 26.491	120 Z	+0 42	+ 9.64	− 4.54	+ 5.10	26	±3.2
660	1906, Apr. 9.450	120 Z	+0 39	+16.21	−11.36	+ 4.85	15	2.5
666	1906, Apr. 11.444	105 Z	+0 38	+16.69	−12.29	+ 4.40	15	2.4
684	1906, May 28.371	95 Z	+1 59	+32.99	−27.77	+ 5.22	20	2.5

Mean: + 4.89

ο Virginis

α 12ʰ 0ᵐ1, δ +9° 17′ Type XIV, Mag. 5.03

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\,\Sigma v^2$
308	1905, May 3.438	(130)Z	+1 43	− 6.17	−20.97	−27.14	15	±2.9
674	1906, Apr. 15.458	(135)K	+0 59	−16.11	−13.71	−29.82	13	2.5
943	1907, Apr. 24.445	120 Z	+1 16	−10.01	−17.40	−27.41	14	4.2

Mean: −28.12

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	$1/m\ \Sigma v$
	ε Virginis							
	$\alpha\ 12^h\ 57^m.2$, $\delta + 11°\ 30'$			Type XV, Mag. 4.72				
		min.		km	km	km		km
80*	1903, May 29.385	70 K	$+1^h\ 10^m$	+11.50	−24.02	−12.52	15	±2.4
80	1903, May 29.385	70 K	+1 10	+12.86	−24.02	−11.16	15	2.5
143	1904, Apr. 25.436	65 KZ	+0 13	+ 0.95	−12.36	−11.41	16	1.3
150	1904, May 15.377	65 K	+0 6	+ 5.15	−20.08	−14.93	16	2.3
387	1905, Apr. 14.481	90 Z	+0 32	− 5.36	− 7.30	−12.66	16	1.5
535	1905, Dec. 30.754	65 K	+0 11	−41.90	+29.05	−12.85	32	2.1
682	1906, May 23.394	100 Z	+1 1	+10.25	−22.47	−12.22	22	2.9
689	1906, June 6.381	80 Z	+1 37	+13.34	−25.87	−12.53	22	2.0
					Mean:	−12.54		
	η Boötis							
	$\alpha\ 13^h\ 49^m.9$, $\delta + 18°\ 54'$			Type XIV, Mag. 3.79				
72*	1903, May 23.403	60 K	+0 20	+24.86	−17.70	+ 7.16	14	±1.8
72	1903, May 23.403	60 K	+0 20	+25.69	−17.70	+ 7.99	14	1.7
142	1904, Apr. 24.501	75 KZ	+0 50	+ 4.84:	− 7.02	− 2.18:	14	2.1
147	1904, May 7.480	(60)K	+1 10	+ 8.10	−12.35	− 4.25	16	1.8
405	1905, May 28.407	85 Z	+0 47	+15.98	−19.39	− 3.41	16	2.3
568	1906, Jan. 23.735	60 K	+0 26	−19.51	+25.73	+ 6.22	26	1.7
691	1906, June 7.371	65 Z	+0 33	+25.83	−21.90	+ 3.93	26	2.6
					Velocity variable			
	α Boötis							
	$\alpha\ 14^h\ 11^m.1$, $\delta + 19°\ 42'$			Type XV, Mag. bright				
301	1904, Dec. 21.797	21 K	−0 35	−28.43	+24.03	− 4.40	20	±1.3
427	1905, July 7.349	20 K	+1 40	+21.20	−25.02	− 3.82	20	1.9
570	1906, Jan. 23.787	19 K	+1 20	−29.52	+25.46	− 4.06	20	1.4
623	1906, Mar. 27.597	20 K	+0 53	−12.03	+ 7.58	− 4.45	20	2.0
676	1906, Apr. 15.556	23 K	+1 10	− 2.51	− 0.65	− 3.16	20	1.9
964	1907, July 21.345	26 K	+2 27	+21.79	−25.22	− 3.43	20	1.3
					Mean:	− 3.89		
	ρ Boötis							
	$\alpha\ 14^h\ 27^m.5$, $\delta + 30°\ 49'$			Type XV, Mag. 4.98				
406	1905, May 29.481	100 Z	+2 0	+ 4.13	−15.68	−11.55	15	±2.0
416	1905, June 20.442	120 Z	+2 29	+ 8.48	−20.08	−11.60	11	2.8
690	1906, June 6.460	105 Z	+2 0	+ 6.08	−17.50	−11.42	16	1.3
945	1907, May 9.476	120 Z	+0 31	− 2.84	− 9.53	−12.37	15	2.2
					Mean:	−11.74		

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	$1/\sqrt{\Sigma v}$

ε Boötis, maj. dpl.

α $14^h\ 40^m.6$, δ + 27° 30′ Type XV, Mag. bright

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	$1/\sqrt{\Sigma v}$
		min.		km	km	km		km
82*	1903, May 31.455	60 K	$+1^h16^m$	− 0.86	−15.00	−15.86	14	±3.3
82	1903, May 31.455	60 K	+1 16	+ 0.49	−15.00	−14.51	14	2.2
144	1904, Apr. 25.524	60 KZ	+0 35	− 8.25:	− 3.06	−11.31:	15	1.6
208	1904, June 26.408	62 K	+1 53	+ 5.82	−20.72	−14.90	16	1.5
418	1905, June 22.415	60 K	+1 46	+ 4.34	−20.06	−15.72	14	2.0
625	1906, Mar. 27.661	75 K	+1 56	−25.72	+ 8.04	−17.68	28	1.8

Velocity variable?

β Ursae minoris

α $14^h\ 51^m.0$, δ + 74° 34′ Type XVI, Mag. 4.09

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	$1/\sqrt{\Sigma v}$
105*	1903, July 2.492	75 K	+4 5	+22.27	− 4.62	+17.65	14	±2.9
105	1903, July 2.492	75 K	+4 5	+23.17	− 4.62	+18.55	14	1.7
183	1904, June 13.394	42 KZ	+0 31	+24.14	− 6.57	+17.57	15	2.6
186	1904, June 14.386	60 K	+0 24	+26.29	− 6.48	+19.81	15	1.7
247	1904, Aug. 2.393	63 K	+3 47	+19.50	− 2.81	+16.69	14	2.3
944	1907, May 7.430	(60)Z	−1 6	+28.36	− 8.60	+19.76	17	2.4

Mean: +18.34

β Boötis

α $14^h\ 58^m.2$, δ + 40° 47′ Type XIV, Mag. 4.56

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	$1/\sqrt{\Sigma v}$
71*	1903, May 22.516	90 K	+1 51	−10.42	−10.49	−20.91	14	±2.3
71	1903, May 22.516	90 K	+1 51	− 9.18	−10.49	−19.67	11	2.9
109*	1903, July 15.447	90 K	+3 44	− 2.21	−17.33	−19.54	14	2.6
109	1903, July 15.447	90 K	+3 44	− 1.69	−17.33	−19.02	12	3.0
692	1906, June 7.442	95 Z	+1 8	− 5.89	−13.74	−19.63	17	3.6
947	1907, May 10.453	95 Z	−0 27	−10.42	− 7.37	−17.79	17	2.4

Mean: −19.43

δ Boötis

α $15^h\ 11^m.5$, δ + 33° 42′ Type XV, Mag. 4.72

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	$1/\sqrt{\Sigma v}$
74*	1903, May 24.473	80 K	+0 43	− 2.97	− 9.74	−12.71	14	±2.0
74	1903, May 24.473	80 K	+0 43	− 2.64	− 9.74	−12.38	13	3.3
149	1904, May 13.485	(120)Z	+0 18	− 5.99:	− 6.69	−12.68:	15	2.6
949	1907, May 11.451	110 Z	−0 40	− 3.40	− 5.76	− 9.16	18	2.6

Mean: −11.73

ι Draconis

α $15^h\ 22^m.7$, δ + 59° 19′ Type XV, Mag. 5.02

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	$1/\sqrt{\Sigma v}$
196	1904, June 20.405	100 KZ	+0 42	− 1.01	− 9.48	−10.49	17	±3.2
412	1905, June 3.370	50 Z	−1 16	− 0.13	− 8.79	− 8.92	15	1.9
429	1905, July 7.433	85 Z	+2 28	− 1.47	− 9.38	−10.85	15	1.3
952	1907, May 25.392	(85)Z	−1 22	− 0.27	− 8.13	− 8.40	18	2.4

Mean: − 9.66

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to $\odot$	Radial Velocity	No. of Lines	$1/m\,\Sigma v$
				α Serpentis				
	α 15ʰ 39ᵐ.3, δ +6° 44′			Type XV, Mag. 4.23				
		min.		km	km	km		km
78*	1903, May 26.454	60 K	$-0^h\ 4^m$	+ 9.74	− 6.04	+ 3.70	14	± 2.0
78	1903, May 26.454	60 K	−0 4	+11.31	− 6.04	+ 5.27	13	1.5
81*	1903, May 30.473	60 K	+0 40	+13.59	− 7.84	+ 5.75	15	1.7
81	1903, May 30.473	60 K	+0 40	+12.12	− 7.84	+ 4.28	14	1.5
213	1904, June 29.410	73 K	+1 9	+23.95	−19.35	+ 4.60	16	2.1
954	1907, June 11.450	75 K	+0 53	+17.39	−12.77	+ 4.62	16	1.9
					Mean:	+ 4.70		
				γ Serpentis				
	α 15ʰ 51ᵐ.8, δ +16° 0′			Type XIII*a*, Mag. 4.54				
415	1905, June 19.458	(120)Z	+1 26	+22.21	−14.25	+ 7.96	15	± 1.9
710	1906, July 16.410	120 KZ	+2 1	+27.76	−21.29	+ 6.47	18	2.1
713	1906, July 17.398	120 KZ	+1 48	+28.34	−21.46	+ 6.88	19	1.7
					Mean:	+ 7.10		
				δ Ophiuchi				
	α 16ʰ 9ᵐ.1, δ −3° 26′			Type XVII, Mag. 4.53				
956	1907, June 27.440	100 K	+1 12	− 1.33	−15.71	−17.04	17	± 2.7
958	1907, July 8.410	125 Z	+1 19	+ 1.51	−19.73	−18.22	13	3.0
960	1907, July 19.369	120 Z	+0 56	+ 5.06	−23.06	−18.00	20	2.3
962	1907, July 20.371	120 Z	+1 4	+ 8.27:	−23.33	−15.06:	10	2.2
					Mean:	−17.08		
				η Draconis				
	α 16ʰ 22ᵐ.6, δ +61° 44′			Type XIV ?, Mag. bright				
411	1905, May 31.453	60 Z	−0 27	− 7.68	− 4.86	−12.54	16	± 1.6
425	1905, July 6.456	65 Z	+1 59	− 7.54	− 5.93	−13.47	16	2.0
448	1905, July 29.385	(90)K	+1 47	− 6.07	− 5.45	−11.52	17	2.4
955	1907, June 27.367	70 K	−0 48	− 8.08	− 5.77	−13.85	24	1.6
					Mean:	−12.84		
				β Herculis				
	α 16ʰ 25ᵐ.9, δ +21° 42′			Type XV, Mag. 4.17				
93*	1903, June 26.383	60 K	−0 30	− 0.76	−12.05	−12.81	14	± 2.5
93	1903, June 26.383	60 K	−0 30	+ 0.45	−12.05	−11.60	16	2.5
164	1904, June 4.463	66 KZ	+0 1	−21.18	− 5.09	−26.27	16	2.2
197	1904, June 20.490	70 Z	+1 41	−13.57	−10.62	−24.19	15	2.2
217	1904, July 4.435	67 K	+1 19	− 6.74	−14.68	−21.42	15	2.0
243	1904, July 23.373	40 K	+1 4	+ 1.61	−18.93	−17.32	16	1.9
					Velocity variable			

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	$1/m\,\Sigma v$
	ζ Herculis							
	α 16^h 37^m.5, $\delta + 31° 47'$			Type XIV, Mag. 3.93				
		min.		km	km	km		km
66*	1903, May 21.491	60 K	$-0^h 29^m$	−73.59	+ 0.36	−73.23	14	±2.2
66	1903, May 21.491	60 K	−0 29	−73.44	+ 0.36	−73.08	16	1.5
83*	1903, May 31.513	60 K	+0 42	−72.43	− 2.71	−75.14	13	1.7
83	1903, May 31.513	60 K	+0 42	−72.12	− 2.71	−74.83	12	2.3
184	1904, June 13.457	60 KZ	+0 15	−65.63	− 6.60	−72.23	16	1.5
238	1904, July 19.378	60 K	+0 44	−56.99	−14.76	−71.75	16	1.9
705	1906, July 2.459	100 Z	+1 31	−60.19	−11.37	−71.56	31	2.2
					Velocity variable			
	η Herculis							
	α 16^h 39^m.5, $\delta + 39° 7'$			Type XV, Mag. 4.65				
233	1904, July 15.407	120 KZ	+1 8	+23.04	−12.05	+10.99	14	±2.1
236	1904, July 18.401	102 Z	+1 11	+21.35	−12.45	+ 8.90	13	2.2
443	1905, July 26.399	105 Z	+1 38	+25.22	−13.37	+11.85	28	2.8
967	1907, July 24.402	120 Z	+1 33	+23.71	−13.10	+10 61	20	2.6
					Mean:	+10.59		
	κ Ophiuchi							
	α 16^h 52^m.9, $\delta + 9° 32'$			Type XV, Mag. 4.56				
187	1904, June 14.470	95 KZ	+0 23	−49.95:	− 5.47	−55.42:	15	±2.7
202	1904, June 21.487	95 KZ	+1 15	−43.89	− 8.36	−52.25	15	1.5
230	1904, July 12.414	104 KZ	+0 53	−37.58	−15.96	−53.54	13	1.7
453	1905, Aug. 3.395	100 Z	+1 51	−31.65	−21.87	−53.52	17	1.9
					Mean:	−53.68		
	π Herculis							
	α 17^h 11^m.6, $\delta + 36° 55'$			Type XV, Mag. 4.98				
204	1904, June 23.481	96 Z	+0 55	−16.52	− 5.40	−21.92	9	±2.7
211	1904, June 27.484	(100)K	+1 15	−17.20	− 6.35	−23.55	13	3.0
249	1904, Aug. 3.383	93 K	+1 15	−10.83	−13.05	−23.88	14	1.9
959	1907, July 14.436	(110)Z	+1 10	−13.32	− 9.74	−23.06	17	2.8
					Mean:	−23.10		
	β Draconis							
	α 17^h 28^m.2, $\delta + 52° 23'$			Type XIV, Mag. 4.19				
167	1904, June 6.451	58 KZ	−1 12	−19.62	− 0.56	−20.18	14	±2.3
170	1904, June 7.433	90 KZ	−1 34	−22.35	− 0.67	−23.02	13	2.1
185	1904, June 13.522	62 KZ	+0 59	−18.91	− 1.55	−20.46	15	1.9
244	1904, July 29.390	64 K	+0 49	−13.30	− 6.22	−19.52	16	1.3
965	1907, July 21.453	68 K	+1 46	−14.23	− 5.58	−19.81	18	2.3
					Mean:	−20.60		

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\,\Sigma v$
				β Ophiuchi				
	α 17^h 38^m.5, δ +4° 36′			Type XV, Mag. 4.19				
		min.		km	km	km		km
86*	1903, June 15.491	75 K	$+0^h 10^m$	−12.00	+ 0.27	−11.73	14	±2.2
86	1903, June 15.491	75 K	+0 10	−11.67	+ 0.27	−11.40	14	2.3
96*	1903, June 27.500	75 K	+1 10	− 4.11	− 5.04	− 9.15	13	2.6
96	1903, June 27.500	75 K	+1 10	− 4.47	− 5.04	− 9.51	14	2.0
165	1904, June 4.531	90 KZ	+0 26	−15.70	+ 4.69	−11.01	15	2.0
240	1904, July 21.392	80 K	+0 12	+ 5.15	−14.83	− 9.68	15	1.5
					Mean:	−10.41		
				μ Herculis				
	α 17^h 42^m.5, δ +27° 47′			Type XIV, Mag. 4.39				
239	1904, July 19.446	93 Z	+1 18	− 4.51	−10.13	−14.64	16	±2.0
242	1904, July 22.412	94 Z	+0 41	− 3.67	−10.86	−14.53	16	1.8
439	1905, July 20.430	(65)Z	+0 57	− 2.67	−10.30	−12.97	17	2.6
450	1905, July 31.405	90 Z	+1 4	− 2.89	−12.96	−15.85	15	1.7
					Mean:	−14.50		
				ξ Draconis				
	α 17^h 51^m.8, δ +56° 53′			Type XV, Mag. 5.34				
423	1905, July 3.489	120 Z	+1 5	−24.08	− 1.56	−25.64	12	±1.5
716	1906, July 23.430	120 Z	+0 58	−22.00	− 3.01	−25.01	17	2.9
718	1906, July 25.363	115 K	−0 31	−23.70	− 3.08	−26.78	23	1.9
					Mean:	−25.81		
				ξ Herculis				
	α 17^h 53^m.9, δ +29° 16′			Type XV, Mag. 4.79				
420	1905, June 23.501	(115)Z	+0 41	+ 2.24	− 1.22	+ 1.02	14	±2.8
433	1905, July 8.503	110 Z	+1 43	+ 4.84	− 5.69	− 0.85	13	1.7
724	1906, July 30.398	120 Z	+0 37	+10.58	−11.29	− 0.71	27	2.1
961	1907, July 19.465	110 Z	+1 29	+ 8.77	− 8.55	+ 0.22	19	1.8
					Mean:	− 0.08		
				γ Draconis				
	α 17^h 54^m.3, δ +51° 30′			Type XVI, Mag. 4.45				
85*	1903, June 11.494	85 K	−0 17	−28.04	+ 0.95	−27.09	14	±2.2
85	1903, June 11.494	85 K	−0 17	−28.06	+ 0.95	−27.11	13	2.1
168	1904, Jnne 6.503	75 KZ	−0 21	−27.69	+ 1.49	−26.20	15	1.9
171	1904, June 7.497	85 KZ	−0 26	−26.54	+ 1.38	−25.16	16	1.0
245	1904, July 29.445	73 K	+1 43	−21.60	− 4.99	−26.59	15	2.3
					Mean:	−26.43		

Plate No.	Date Greenwich M. T.	Expo-sure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\Sigma v$

η Serpentis

α 18h 16m.1, δ − 2° 56′ Type XV, Mag. 4.62

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\Sigma v$
		min.		km	km	km		km
220	1904, July 6.468	115 Z	+0h 24m	+16.94	− 4.83	+12.11	11	±2.6
228	1904, July 11.460	125 Z	+0 32	+18.28	− 7.10	+11.18	13	1.8
747	1906, Aug. 28.346	115 Z	+0 56	+33.54	−24.21	+ 9.33	14	3.1
963	1907, July 20.468	120 Z	+1 16	+21.34	−10.78	+10.56	12	2.1

Mean: +10.80

χ Draconis

α 18h 22m.9, δ + 72° 41′ Type XIII*a*, Mag. 4.24

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\Sigma v$
726	1906, Aug. 2.358	90 Z	−0 38	+13.49	+ 2.71	+16.20	16	±1.8
728	1906, Aug. 6.361	90 Z	−0 17	+12.55	+ 2.84	+15.39	17	1.7
731	1906, Aug. 7.343	80 Z	−0 38	+13.49	+ 2.86	+16.35	21	2.3
772	1906, Sept. 26.285	(80)Z	+1 14	+29.76	+ 3.12	+32.88	14	2.9
974	1907, Aug. 25.362	90 Z	+0 59	+33.43	+ 3.20	+36.63	15	2.1

Velocity variable

δ Draconis

α 19h 12m.5, δ + 67° 29′ Type XV, Mag. 4.69

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\Sigma v$
232	1904, July 14.449	92 Z	−0 29	+21.33	+ 3.62	+24.95	15	±1.7
234	1904, July 16.413	83 Z	−1 13	+21.35	+ 3.63	+24.98	15	2.6
426	1905, July 6.517	60 Z	+0 37	+21.50	+ 3.61	+25.11	15	2.1
764	1906, Sept. 12.330	80 Z	+0 34	+24.09	+ 1.58	+25.67	20	2.1

Mean: +25.18

κ Cygni

α 19h 14m.8, δ + 53° 11′ Type XV, Mag. 4.94

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\Sigma v$
441	1905, July 21.426	115 Z	−0 37	−29.66	+ 2.13	−27.53	16	±1.2
479	1905, Sept. 22.354	105 Z	+1 47	−20.95	− 6.07	−27.02	16	1.5
733	1906, Aug. 8.378	115 Z	−0 37	−27.61	− 0.29	−27.90	26	2.2
786	1906, Oct. 22.261	120 Z	+1 31	−20.42	− 8.15	−28.57	19	2.0

Mean: −27.76

β Cygni, maj. dpl.

α 19h 26m.7, δ + 27° 45′ Type XV, Mag. 4.31

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\Sigma v$
103*	1903, July 1.570	90 K	+1 18	−29.48	+ 6.78	−22.70	13	±1.7
103	1903, July 1.570	90 K	+1 18	−29.79	+ 6.78	−23.01	14	1.8
224	1904, July 8.465	82 Z	−0 44	−25.05:	+ 4.55	−20.50:	14	3.8
226	1904, July 10.466	87 Z	−0 35	−27.33	+ 3.91	−23.42	14	1.8
757	1906, Sept. 3.378	85 K	+0 54	−11.25	−12.84	−24.09	15	2.0

Mean: −22.74

γ *Aquilae*

α 19h 41m.5, δ +10° 22′ Type XV, Mag. 4.66

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	1/m Σv
		min.		km	km	km		km
97*	1903, June 28.500	75 K	-0^h50^m	−10.17	+10.08	− 0.09	13	±2.2
97	1903, June 28.500	75 K	−0 50	− 9.91	+10.08	+ 0.17	11	2.5
231	1904, July 12.519	84 Z	+0 36	− 3.85	+ 3.99	+ 0.14	13	2.5
472	1905, Sept. 17.354	90 Z	+1 0	+20.80	−20.95	− 0.15	13	1.9
483	1905, Sept. 28.329	(75)Z	+1 8	+23.14	−23.33	− 0.19	16	2.4
759	1906, Sept. 4.365	100 Z	+0 23	+16.00	−17.10	− 1.10	15	2.3
781	1906, Oct. 10.282	95 Z	+0 46	+22.29	−24.98	− 2.69	15	2.5

Mean: − 0.56

ϵ *Draconis*

α 19h 48m.5, δ +70° 1′ Type XIV ?, Mag. 4.95

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	1/m Σv
430	1905, July 7.516	95 Z	+0 2	− 0.44	+ 5.13	+ 4.69	13	±2.3
719	1906, July 25.460	(110)Z	−0 7	− 2.23	+ 5.34	+ 3.11	18	2.6
723	1906, July 29.442	120 Z	−0 18	− 1.75	+ 5.33	+ 3.58	18	2.6
755	1906, Sept. 1.330	120 Z	−0 44	+ 0.10	+ 4.27	+ 4.37	24	2.2

Mean: + 3.94

β *Aquilae*

α 19h 50m.4, δ +6° 10′ Type XV, Mag. 4.83

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	1/m Σv
444	1905, July 26.491	100 Z	+0 40	−36.10	− 1.20	−37.30	15	±2.2
462	1905, Aug. 17.388	120 Z	−0 21	−26.86	−10.58	−37.44	17	2.2
714	1906, July 17.511	120 Z	+0 32	−43.15	+ 2.89	−40.26	17	2.1
985	1907, Sept. 19.360	125 Z	+1 6	−17.07	−21.91	−38.98	16	2.1

Mean: −38.50

η *Cygni*

α 19h 52m.6, δ +34° 49′ Type XV, Mag. 5.06

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	1/m Σv
458	1905, Aug. 13.407	120 Z	−0 12	−22.38	− 2.82	−25.20	18	±1.7
488	1905, Oct. 16.307	118 Z	+1 36	− 9.17	−16.70	−25.87	16	2.0
732	1906, Aug. 7.458	120 Z	+0 36	−24.99	− 1.06	−26.05	14	3.1
741	1906, Aug. 22.351	120 Z	−0 59	−18.77	− 5.21	−23.98	20	3.0

Mean: −25.27

31 *Cygni*

α 20h 10m.5, δ +44° 26′ Type XV, Mag. 5.16

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	1/m Σv
460	1905, Aug. 14.383	120 Z	−1 1	− 3.24	+ 1.12	− 2.12	16	±2.0
711	1906, July 16.546	(90)Z	+0 59	−16.02:	+ 7.04	− 8.98:	9	3.6
717	1906, July 23.535	115 Z	+1 10	−18.49:	+ 5.69	−12.80:	10	1.6
725	1906, July 30.521	120 Z	+1 18	−16.24	+ 4.28	−11.96	18	2.9

Velocity variable

γ Cygni

α 20h 18m.6, δ +39° 56′ Type XIII*c*, Mag. 3.16

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	1/m Σv
		min.		km	km	km		km
92*	1903, June 25.508	75 K	−1h 27m	−20.30	+12.34	− 7.96	13	±4.1
92	1903, June 25.508	75 K	−1 27	−19.52	+12.34	− 7.18	14	2.3
235	1904, July 16.485	53 K	−0 35	−12.44	+ 7.82	− 4.62	15	2.2
246	1904, July 29.506	48 K	+0 47	−10.44	+ 4.53	− 5.91	16	3.4
248	1904, Aug. 2.481	35 K	+0 25	− 8.69	+ 3.52	− 5.17	16	3.0
449	1905, July 29.507	(48) K	+0 46	−10.79	+ 4.60	− 6.19	15	3.3
761	1906, Sept. 8.384	55 K	+0 30	− 0.87	− 6.19	− 7.06	27	3.1

Mean: − 6.30

ε Cygni

α 20h 42m.2, δ +33° 36′ Type XV, Mag. 3.85

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	1/m Σv
237	1904, July 18.487	53 K	−0 48	−24.13	+ 9.66	−14.47	16	±1.4
274	1904, Oct. 14.411	52 K	+3 10	+ 2.11	−16.21	−14.10	28	2.0
284	1904, Oct. 29.249	52 K	+0 15	+ 3.10	−18.38	−15.28	16	1.0
482	1905, Sept. 24.365	(60) K	+0 44	− 2.50	−11.30	−13.80	26	1.6
498	1905, Nov. 6.250	(60) K	+0 47	+ 6.89	−19.16	−12.27	29	1.9
767	1906, Sept. 23.406	55 K	+1 38	+ 4.88	−11.03	− 6.15	26	2.1

Velocity variable

η Cephei

α 20h 43m.3, δ +61° 27′ Type XV, Mag. 4.88

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	1/m Σv
263	1904, Aug. 29.371	100 Z	−0 50	−90.41	+ 4.15	−86.26	16	±1.2
273	1904, Oct. 14.322	93 KZ	+1 1	−82.27	− 3.02	−85.29	15	1.7
275	1904, Oct. 15.262	87 Z	−0 21	−82.89	− 3.12	−86.01	15	1.1
752	1906, Aug. 30.374	92 Z	−0 44	−90.44	+ 4.08	−86.36	18	1.8

Mean: −85.98

ζ Cygni

α 21h 8m.7, δ +29° 49′ Type XV, Mag. 4.42

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	1/m Σv
276	1904, Oct. 16.260	92 Z	−0 46	+31.37	−17.01	+14.36	15	±1.5
286	1904, Oct. 30.317	72 K	+1 30	+34.61	−19.92	+14.69	16	1.7
467	1905, Aug. 24.399	100 Z	−0 56	+14.19	+ 0.06	+14.25	19	1.3
758	1906, Sept. 3.456	90 Z	+1 4	+19.34:	− 3.64	+15.70:	20	4.3

Velocity variable

β Aquarii

α 21h 26m.3, δ −6° 1′ Type XIV, Mag. 4.20

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	1/m Σv
282	1904, Oct. 28.280	100 Z	+0 13	+34.64	−28.47	+ 6.17	14	±1.0
292	1904, Nov. 15.243	103 Z	+0 29	+36.10	−29.78	+ 6.32	15	1.5
754	1906, Aug. 31.453	100 Z	+0 30	+15.74	− 8.23	+ 7.51	25	2.4
771	1906, Sept. 25.384	100 KZ	+0 29	+25.80	−19.20	+ 6.60	22	2.9

Mean: + 6.65

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	$1/m\,\Sigma v$
				ρ Cygni				
	α 21^h 30^m.2, δ +45° 9′			Type XV, Mag. 5.09				
		min.		km	km	km		km
475	1905, Sept. 18.359	130 Z	−0^{h}37^m	+11.85	− 2.15	+ 9.70	15	±2.5
737	1906, Aug. 12.557	125 Z	+1 40	+ 1.83	+ 8.00	+ 9.83	17	2.6
739	1906, Aug. 21.551	(125)Z	+2 7	+ 2.53	+ 5.67	+ 8.20	17	2.5
995	1907, Sept. 25.331	120 Z	−0 51	+13.63	− 3.95	+ 9.68	17	2.5
					Mean:	+ 9.35		
				ε Pegasi				
	α 21^h 39^m.3, δ +9° 25′			Type XV, Mag. 4.41				
280	1904, Oct. 27.345	80 Z	+1 29	+31.24	−25.12	+ 6.12	14	±3.1
285	1904, Oct. 29.314	72 Z	+0 51	+31.33	−25.48	+ 5.85	14	2.1
491	1905, Oct. 20.293	105 Z	−0 15	+30.04	−23.23	+ 6.81	14	2.1
493	1905, Oct. 24.298	100 Z	+0 8	+30.23	−24.27	+ 5.96	12	1.5
1000	1907, Sept. 28.327	90 K	−0 54	+21.15	−15.68	+ 5.47	14	1.8
					Mean:	+ 6.04		
				α Aquarii				
	α 22^h 0^m.6, δ −0° 48′			Type XIV, Mag. 4.35				
297	1904, Nov. 24.233	100 Z	+0 16	+36.53	−29.65	+ 6.88	15	±1.4
520	1905, Dec. 10.203	50 K	+0 34	+34.43	−28.55	+ 5.88	15	1.7
524	1905, Dec. 18.203	106 Z	+1 7	+34.59	−27.17	+ 7.42	16	1.9
787	1906, Oct. 22.364	120 KZ	+1 12	+32.32	−24.86	+ 7.46	16	3.2
					Mean:	+ 6.91		
				ι Pegasi				
	α 22^h 2^m.4, δ +24° 51′			Type XII*a*, Mag. 4.44				
518	1905, Dec. 6.226	80 Z	+0 50	+ 7.27	−25.01	−17.74	18	±1.7
734	1906, Aug. 8.481	105 Z	−0 56	−31.66	+11.12	−20.54	17	2.6
762	1906, Sept. 8.460	100 Z	+0 36	−27.78	− 1.39	−29.17	18	2.0
768	1906, Sept. 24.430	100 Z	+0 56	+44.49	− 7.97	+36.52	16	4.2
979	1907, Sept. 7.496	100 Z	+1 24	+46.84	− 0.92	+45.92	18	2.4
986	1907, Sept. 19.437	(70)Z	+0 46	+29.64	− 5.83	+23.81	10	3.4
987	1907, Sept. 20.444	100 Z	+0 59	+ 3.01	− 6.25	− 3.24	15	2.1
988	1907, Sept. 22.422	100 Z	+0 36	−43.29	− 7.03	−50.32	17	1.9
990	1907, Sept. 23.410	100 Z	+0 23	−41.98	− 7.41	−49.39	16	1.7
994	1907, Sept. 24.405	100 Z	+0 19	−27.55	− 7.81	−35.36	14	2.8
996	1907, Sept. 25.433	90 Z	+1 4	+ 0.85	− 8.28	− 7.43	15	2.5
998	1907, Sept. 26.419	(75)Z	+0 48	+30.15	− 8.65	+21.50	13	2.7
1001	1907, Sept. 28.412	90 Z	+0 45	+51.12	− 9.43	+41.69	11	2.5
					Velocity variable			
				ζ Cephei				
	α 22^h 7^m.4, δ +57° 43′			Type XVI ?, Mag. 5.25				
742	1906, Aug. 22.456	120 Z	−0 42	−26.48	+ 9.73	−16.75	14	±2.4
750	1906, Aug. 29.449	110 Z	−0 26	−24.82	+ 8.43	−16.39	18	2.6
756	1906, Sept. 1.435	120 KZ	−0 34	−24.21	+ 7.84	−16.37	16	2.5
978	1907, Sept. 7.409	120 Z	−0 47	−22.39	+ 6.66	−15.73	16	2.0
					Velocity variable			

η Pegasi

α $22^h\ 38^m.3$, $\delta + 29°\ 42'$ Type XIV, Mag. 4.16

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	$1/m\,\Sigma v$
		min.		km	km	km		km
279	1904, Oct. 23.423	80 Z	$+2^h\ 7^m$	+24.82	−14.73	+10.09	15	±1.8
294	1904, Nov. 16.307	72 Z	+0 54	+34.38	−21.46	+12.92	14	1.9
306	1904, Dec. 23.256	95 Z	+2 7	+42.61	−24.69	+17.92	15	2.3
776	1906, Oct. 8.413	80 Z	+0 50	+ 9.21	− 8.89	+ 0.32	19	2.4

Velocity variable

μ Pegasi

α $22^h\ 45^m.2$, $\delta + 24°\ 5'$ Type XV, Mag. 4.73

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	$1/m\,\Sigma v$
288	1904, Nov. 10.339	120 Z	+1 10	+37.15	−21.73	+15.42	15	±2.3
298	1904, Dec. 21.233	100 Z	+1 18	+42.96	−26.27	+16.69	14	1.2
763	1906, Sept. 11.480	120 Z	+0 34	+ 9.58	+ 1.70	+11.28	18	2.6
984	1907, Sept. 18.476	118 Z	+0 54	+15.48	− 1.28	+14.20	21	2.1

Velocity variable ?

ι Cephei

α $22^h\ 46^m.1$, $\delta + 65°\ 40'$ Type XV, Mag. 4.95

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	$1/m\,\Sigma v$
729	1906, Aug. 6.544	115 Z	−0 17	−25.32	+13.21	−12.11	27	±1.7
753	1906, Aug. 30.465	120 Z	−0 36	−21.57	+11.08	−10.49	26	2.1
765	1906, Sept. 12.420	100 Z	−0 49	−20.58	+ 9.11	−11.47	26	1.8
981	1907, Sept. 10.416	120 Z	−1 4	−19.91	+ 9.49	−10.42	17	3.3

Mean: −11.12

β Pegasi

α $22^h\ 58^m.9$, $\delta + 27°\ 32'$ Type XVIII, Mag. 4.80

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	$1/m\,\Sigma v$
521	1905, Dec. 17.256	95 K	+1 21	+36.45	−25.95	+10.50	20	±2.2
532	1905, Dec. 27.252	100 K	+1 55	+36.32	−25.81	+10.51	18	2.1
775	1906, Oct. 7.439	100 Z	+1 3	+17.83	− 7.36	+10.47	16	2.9
784	1906, Oct. 11.421	120 Z	+0 54	+18.24	− 9.02	+ 9.22	15	3.6

Mean: +10.17

γ Piscium

α $23^h\ 12^m.0$, $\delta + 2°\ 44'$ Type XV, Mag. 5.03

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ⊙	Radial Velocity	No. of Lines	$1/m\,\Sigma v$
283	1904, Oct. 28.371	122 KZ	+0 37	+ 8.41	−21.35	−12.94	14	±1.3
514	1905, Dec. 1.290	120 KZ	+0 54	+15.21	−29.50	−14.29	17	2.2
796	1906, Nov. 11.346	130 KZ	+0 54	+11.53	−25.68	−14.15	14	2.0
1003	1907, Oct. 10.408	120 Z	+0 17	−0. 03	−13.56	−13.59	14	1.5

Mean: −13.74

Plate No.	Date Greenwich M. T.	Exposure	Hour Angle	Observed Velocity	Red. to ☉	Radial Velocity	No. of Lines	$1/m\Sigma v$
			λ Andromedae					
	α 23^h 32^m.7, δ +45° 55′			Type XV, Mag. 5.00				
		min.		km	km	km		km
780	1906, Oct. 9.398	120 Z	-0^h22^m	+ 7.66	+ 0.16	+ 7.82	18	±3.0
792	1906, Nov. 10.282	120 Z	−1 3	+25.08	−11.21	+13.87	20	2.5
800	1906, Nov. 20.255	120 Z	−1 2	+20.58	−14.27	+ 6.31	19	1.9
816	1906, Dec. 22.248	120 Z	+0 55	+34.87	−20.95	+13.92	20	2.4
					Velocity variable			
			γ Cephei					
	α 23^h 35^m.2, δ +77° 4′			Type XV, Mag. 4.87				
506	1905, Nov. 28.247	100 Z	−0 44	−39.57	− 1.69	−41.26	23	±1.6
509	1905, Nov. 30.223	100 Z	−1 10	−39.48	− 2.13	−41.61	16	1.1
766	1906, Sept. 13.480	100 Z	−0 8	−54.28	+11.72	−42.56	16	2.5
782	1906, Oct. 10.387	95 Z	−0 34	−49.29	+ 8.42	−40.87	16	1.9
1002	1907, Oct. 4.407	90 Z	−0 38	−51.39	+ 9.40	−41.99	19	1.7
					Mean:	−41.66		

Among these 99 stars there are 15 with previously known variable velocities; there are three others:

δ Tauri, *ε Boötis*, and *μ Pegasi*

of which it is suspected that their velocities vary.

For the remaining 81 stars the mean values for the plates are given above, no plate that was measured having been omitted. A few plates which were taken under especially unfavorable circumstances are designated as uncertain by the symbol : ; but these plates enter with their full value into the mean. The total number of the plates of these 81 stars is 355, and the sum of the squares of the deviations of the separate plates from the mean is computed to be 249.75. From this follows:

$$\text{Probable error of a plate} = 0.6745\sqrt{\frac{249.75}{274}} = \pm 0.64 \text{ km.}$$

This probable error will presumably be somewhat diminished in the definitive discussion, when the relative corrections for the wave-lengths of the star lines, provisionally taken from Rowland's solar lines, are computed. Since the whole series contains in round numbers 7500 complete measures of about 44 different stellar lines, it will be possible to obtain a very sharp determination of the relative wave-lengths of these lines and at the same time of their dependence

on the type. It is to be expected, however, that the above mean of the radial velocities will not be very much altered by these relative corrections to the lines, inasmuch as the mean for each separate star depends upon a large number of different lines.

Perhaps of somewhat more considerable amount will be found the constant correction which is further to be applied to the observed radial velocities, due in the first place to the absolute errors of the wave-lengths for the *Fe* lines and the star lines taken from Kayser and from Rowland; and in the second place to the combined effect of the instrumental and personal errors which come into play in making and in measuring the spectrograms. It is customary to determine this constant correction by control plates of the sun, moon, or larger planets, and to compare the observed radial velocities with those given precisely by theory. I regard this control as by no means valid, inasmuch as the light used in such cases proceeds from a surface and uniformly illuminates the entire area of the collimating lens; while the star's light, with the very small slit-width necessary, illuminates only a diametral strip with a maximum of intensity along the middle line. The path of the rays is therefore decidedly different in the two cases. *An exact test of the observed radial velocities of stars can in my opinion be obtained only by the observation of a source of light of precisely known radial velocity and as similar as possible to a star, under conditions as closely as possible the same in the observation of the star.*

For instruments of great light-power, with which faint stars can be spectrographically observed, the brightest of the minor planets are especially adapted for this purpose, and perhaps also the satellites of *Jupiter*. Otherwise such a starlike source of light could be most readily produced artificially by a heliotrope set at a sufficiently great distance, as such are used in geodetic triangulations. This could not be attempted at Bonn readily, as the photographic refractor does not permit a view toward distant mountains: it would be necessary to reflect the light from the heliotrope by a second large plane mirror at the central tower of the Observatory, a troublesome procedure which did not appear to be above suspicion.

I had further thought of removing the objective of the refractor, and substituting for it in front of the spectrograph a precisely similar

but some twenty times smaller objective, in order to throw upon the slit a stellar image of one of the larger planets. The brightness of this image would be according to computation sufficient for obtaining a good spectrogram with an exposure of from one to two hours. This procedure, however, also seemed somewhat troublesome, since the large objective had to be removed.

Finally in our repeated discussions of the problem, the idea occurred to Mr. Zurhellen whether it would not be possible to photograph with the spectrograph the starlike, isolated luminous mountain peaks on the night side of the moon near the terminator. We at once made the experiment, which was successful. Unfavorable weather and the circumstance that suitable objects are not always to be found at the terminator, have permitted us to make thus far only the following observations. The exposure and the measurement were made in precisely the same manner as for stars, and the spectrograms do not differ in appearance from those of the stars.

SPECTROGRAMS OF ISOLATED PEAKS NEAR THE TERMINATOR OF THE MOON

Plate No.	Date G. M. T.	Exposure	Hour Angle	Observed Velocity	Calculated Velocity	$C-O$	No. of Lines	$1/m\ \Sigma\nu$
		min.		km	km	km		km
1038	1908, Jan. 15.435	65 Z	$+0^h49^m$	+1.12	+0.63	−0.49	18	+1.7
1042	1908, Feb. 10.269	100 Z	−0 19	+2.80	+1.20	−1.60	21	2.1
1043	1908, Feb. 10.351	75 K	+1 37	+3.54	+1.33	−2.21	19	1.7
1045	1908, Feb. 11.378	80 K	+1 28	+1.18	+1.24	+0.06	16	2.1

Mean: −1.06

We shall continue further this series of plates of the lunar mountains until we obtain a fully established value for $C-O$. We may assume from these few determinations *that the radial velocities of the stars communicated above require a small negative correction amounting to about −1.0 km.* The correction, when thus determined, will fully eliminate all instrumental and personal errors of the exposure and the measurement, as well as the errors in the assumption of the wavelengths in the comparison light and that of the stars, so that we obtain the correct absolute radial velocities of the stars.

ROYAL OBSERVATORY, BONN
February 1908

AN EXPERIMENTAL STUDY OF THE LIPPMANN COLOR PHOTOGRAPH

By HERBERT E. IVES

Photography in colors by means of standing light-waves was first accomplished by E. Becquerel about 1850, although he was unaware of the part they played in his results. Zenker[1] developed the theory that the polished silver surface, on which Becquerel's sensitive film was formed, reflecting the incident light, caused standing waves. In the loops of these waves the silver salt was reduced, forming parallel reflecting surfaces distant from each other one-half the wave-length of the incident light. Viewed by reflection, the developed film exhibited color as do thin films of oil on water, or, more exactly, the multiple interior surfaces of potassium chlorate crystals.[2]

Lippmann[3] in 1891 was the first to make practical application of this theory by developing the process of color-photography bearing his name. For the polished silver surface of Becquerel he substituted mercury, which could be flowed behind a transparent fine-grain sensitive film on glass during the exposure, and removed to permit development and the subsequent viewing.

The theory and practice of the process will be found discussed by Lippmann,[4] Wiener,[5] Neuhaus,[6] Valenta,[7] Lehmann,[8] and others.[9] Full use has been made in the following study of the results of their work, and details of theory and experimental methods not new with the writer will not be described at any length.

Good results have been obtained by the process as worked by these

[1] *Lehrbuch der Photochromie*, 1868.

[2] *Rayleigh, Phil. Mag.* (5), **26**, 256, 1888.

[3] *Comptes rendus*, **112**, 274, 1891.

[4] *Journal de Physique*, **3**, 97, 1894.

[5] *Annalen der Physik*, **69**, 488, 1899.

[6] *Die Farbenphotographie nach Lippmann's Verfahren*, 1898.

[7] *Die Photographie in natürlichen Farben*, 1894.

[8] *Beiträge zur Theorie und Praxis der directen Farbenphotographie*, **1**, 1906.

[9] A historical account of the development of the process will be found in *Die Grundlagen der Farbenphotographie*, by B. Donath, 1906.

and other experimenters, but its difficulties have been found so great as to prevent its wide use. Some discrepancies with the theory have been found, and compromises with the best conditions as indicated by theory have been found necessary in practice.

The object of the present investigation has been to see how closely the conditions called for by theory could be approached, to find the cause of some of the difficulties met with in practice, and, if possible, to obviate these.

The separate problems will be stated as they are taken up, but may be briefly outlined here.

According to the theory as stated by Lippmann the most accurate reproduction of color should come from the use of a thick sensitive film, the film gaining in resolving power with the number of reflecting laminae. In practice very thin films have been used; reproductions of the spectrum show, on examination with the spectroscope, that the colors are very far from pure. The first investigation which follows was to determine whether films could not be prepared which would reproduce colors with a fidelity much greater than has hitherto been possible and whose thickness could be increased with corresponding increase in resolving power. The investigation has resulted in a method for producing films having these characteristics.

The production of pictures of natural objects has been a matter of uncertainty and difficulty; the production of whites has been a stumbling-block to many. The manipulation of the plates with the necessity for a mercury-holding plate-holder has been inconvenient. The causes of this uncertainty in results have been studied; the conditions governing the production of white fixed; and a substitute found for the hitherto indispensable mercury mirror.

In addition, an application of the process to three-color photography has been developed.

MANIPULATION OF PLATES IN GENERAL

The transparent fine-grain silver bromide plates were made, with only such changes as are noted, according to the published formulae of Lippmann, Neuhaus, and Valenta. Ordinary "chemically pure" silver nitrate and potassium bromide were used; the gelatine was either Eimer & Amend's "Gold Label," Nelson's "No. I," or a de-

partment store gelatine recommended as the best for puddings, etc., which was found very hard and free from grease. The emulsion was flowed on pieces of crystal plate glass cut three by three inches. A plate-holder not greatly different from that used by previous workers permitted the introduction of mercury behind the plate and in contact with the gelatine.

The scheme of exposure followed throughout was to expose a comparatively large surface (two by two inches) to the kind of light being investigated. This allowed of easy spectroscopic examination besides leaving room for stripping portions to be sectioned.

Development was mostly with pyrogallic acid and ammonia according to the formula of Valenta, with the one change that the pyrogallic acid was used in powder form, added by means of a spoon of proper capacity to the rest of the developer just before use with each plate. The resulting developer was always fresh and of uniform strength. The hydroquinone used in part of the work was made up according to Jewell's formula[1] with the omission of the potassium ferrocyanide.

After development and drying, the pictures were made ready for viewing by cementing a thin prism of small angle on the film to destroy the disturbing surface reflections, and the back of the glass was flowed with asphaltum varnish. The prism is usually cemented on by means of Canada balsam. As, however, the refractive index of the gelatine containing reduced silver is somewhat higher than that of the balsam, some medium of higher index is to be preferred. Gum styrax ($\mu = 1.58$) was found suitable, but the lower surface of the prism must be ground to avoid the reflection at glass-balsam surface. The latter procedure was uniformly adopted. The amount of light reflected from the laminae is at best small, so to obtain the purest colors all addition of white light is to be avoided. This white light may come from the prism-balsam, balsam-gelatine, gelatine-glass, or rear glass surfaces, and if all these reflections are not diminished as much as possible the dilution of colors is quite appreciable. The prism-balsam reflection is overcome by grinding the back of the prism with emery; the balsam-gelatine by correct choice of balsam; the gelatine-glass is unavoidable; the reflection from the back of the glass

[1] *Astrophysical Journal*, **11**, 242, 1900.

can be destroyed completely by first grinding with emery and then flowing on asphaltum varnish, preferably mixed with machine oil to prevent its becoming brittle and flaking off. If the pictures are to be observed from the glass side, a second prism is cemented on in place of the black varnish.

When so mounted the pictures are ready for observation. It is of extreme importance that they be observed by parallel light and shielded from all side light. The best conditions are given by a small opening in a wall facing a brilliant white sky. If the observer stands with his back to the opening and holds the picture at arm's length reflecting the sky it appears at its best.

These precautions are most necessary in the case of pictures of natural objects, for reasons which will appear later. Spectra and similar subjects, where the reflecting laminae are numerous and deep in the film, are visible much more easily, but are of course best seen under the conditions given above.

WORK WITH MONOCHROMATIC LIGHT SOURCES

The first investigation was on the influence of two factors, fineness of grain, and film thickness, upon the correctness of color rendering. It is naturally to be expected that both factors will influence this. The smaller the silver particles the more minute the variations in the standing wave-system they will record. The thicker the film the more laminae and hence the greater purity of the reflected light.

There are comparatively few recorded experiments on variations in the size of the grain; the first published emulsion formulae have been closely followed by all experimenters. Cajal[1] recently observed that the size of the grain is influenced largely by the amount of agitation of the emulsion during preparation, and finds that the finer the grain the better the quality of the colors. He, however, was not working with pure spectrum colors. The present investigation of this point was prompted by the observation that when photographing monochromatic light sources for a special application of the process, the use of much less silver bromide gave more satisfactory results. This made it appear of interest to determine from this standpoint the best proportion of silver salt.

[1] *Zeitschrift für wissenschaftliche Photographie*, **5**, 213–245, July 1907.

With regard to the best thickness of film, theory would call for the greatest thickness practicable to work. Yet the practice has been to work with extremely thin ones such as can be obtained by flowing the liquid gelatine on and off a warm glass plate. The section photographed by Neuhaus showed but seven or eight laminae. Wiener, by counting the laminae cutting the gelatine-glass surface in a spectrum photograph, found the number less than twenty, obviously too few to have much resolving power, and explaining the impure reflected light. There has indeed been reason to suppose that appreciably greater thickness would not help matters. The loss of light by absorption and reflection at each lamina is large, so that the effect of each lamina becomes rapidly less with increasing distance from the surface of the film, assuming them all equally well formed. Film sections indicate that the latter is not the case; the laminae are of rapidly decreasing strength. Lehmann has calculated, taking into account the effect of absorption, that the laminae should be more distinct, the greater the distance from the mirror. That they are not he ascribes to the reflected light losing the power of interfering after a short distance. These points were considered worth investigating more closely.

The size of the silver grain was varied entirely by the quantity of silver bromide in the emulsion. A set of emulsions was made up in which the content of silver nitrate varied between 0.03 and 0.18 gram per gram of gelatine, the quantity of potassium bromide constantly five-sixths of this. The resulting emulsion had from one-sixth to the same amount of silver bromide as used by Valenta and others. The emulsion was flowed on the level plates in measured quantities from a graduate, so that the thickness was under control. After flowing, the emulsion was pushed to the corners of the plate by means of a glass rod. The quantity used varied from one to ten cubic centimeters on a 3×3 inch plate. This gave films from about 0.007 to 0.07 mm, as sections afterward showed by the number of contained laminae.

Monochromatic green light was used for the greater part of the work. This was obtained from a Cooper Hewitt mercury vacuum lamp, an aperture of 1 sq cm illuminating the plate 25 cm distant. A cell of neodymium ammonium nitrate and potassium bichromate

absorbed the yellow and blue radiations. The plates were made sensitive to this color by erythrosine.

INFLUENCE OF SIZE OF GRAIN

A noticeable increase of purity in reflected light was found as the quantity of silver bromide was reduced. This increase is quite marked between 0.18 and 0.09 grams of silver nitrate per gram of gelatine, after that less so.

Besides the influence on the purity of the reproduced color the quantity of silver bromide affects the sensitiveness of the plates. A rather unlooked for result was that a smaller quantity of silver salt made the plates more sensitive, up to a certain point. This is readily explained; the light must pass through the film, and decreasing the silver content increases the transparency. If the amount of silver becomes too small the plates again become less sensitive. The fastest emulsion was found to be one containing half the silver salt used by previous workers. As this gave practically all the increase of purity resulting from decreased grain it was adopted as the standard emulsion for future work.

The formula and method of preparation were as follows:

A. Gelatine 1 gram	B. Gelatine 2 grams	C. *AgNO* 0.3 gram
Water 25 cc	*KBr* 0.25 gram	Water 5 cc
	Water 50 cc	

A and B are heated till the gelatine melts, allowed to cool to 40 degrees, C added to A and then A to B slowly with stirring, the sensitizer added, and the whole filtered. After flowing and setting, the plates are washed for fifteen minutes and allowed to dry.

INFLUENCE OF THICKNESS OF FILM

The first work done on the influence of film thickness indicated that, viewed from the film side, there was no increase of purity with increase of thickness beyond one of about thirty half-wave-lengths, or about that given by flowing the emulsion on and off the cold glass plates. The single green line of mercury was rendered as an ill-defined green band in the spectrum, properly a continuous spectrum with strong maximum in the green. Fig. A, II, gives the mercury green line as rendered by the emulsion found best as above. The green light is considerably more monochromatic than that usually seen

in Lippmann spectra. From the glass side the band was of a different character, showing more clearly defined edges, as given in Fig. A, III. This is explained by the stronger laminae being farther from the eye and by absorption being no more effective than the weaker ones. The reflecting surfaces are then comparable to the lines of a grating, each sending equal contributions to the total reflected light. Owing to the strongest laminae suffering so much absorption, the light from the glass side is much weaker than from the film side.

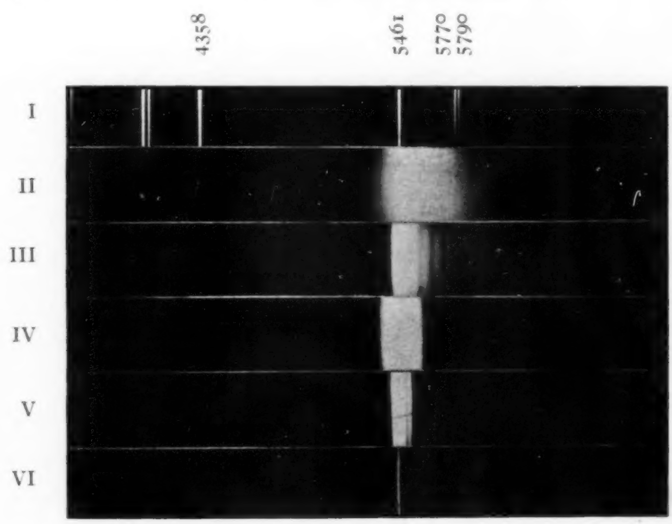

FIG. A

I. Mercury vacuum arc.
II. λ 5461 as reproduced by fine-grain film, with pyrogallic acid development.
III. Same from glass side.
IV, V, VI. Hydroquinone-developed bleached films, 50, 150, 250 laminae.

Even from the glass side, however, increase of thickness beyond the above-given limit produced no corresponding increase of purity. Further light on this question was furnished by studying the effect of varying exposure and development.

EFFECT OF VARYING EXPOSURE

To study this, exposures were made through a graduated wedge of erythrosine solution, opaque to green light. Before noting the effect of varying exposure on the reflected colored light, the appearance of the film at angles other than the angle of specular reflection is worth

describing. By reflected light the film appears in the less exposed parts like an ordinary fine-grain negative, that is, there is a certain amount of diffuse reflection so that a positive image is seen. As the exposure proceeds the diffuse reflection becomes less and less until the film is quite grainless and black, except at the angle of specular reflection, behaving as a piece of unsilvered glass. By transmission the plate is greenish in the very slightly exposed parts, muddy brownish yellowish in the moderately exposed parts; where the film has been exposed until the diffuse light disappears by reflection it is clear, transparent yellow, like a piece of yellow glass. The appearance and behavior of the silver deposit is in all respects as though the particles of silver were first separate, scattering light, and on longer exposure fused together into a homogeneous mass. The appearances here described may be observed on almost any Lippmann photograph viewed at other than the angle to show color, the diffuse deposit forming a positive image which in the fully exposed high-lights appears reversed.

The colored light reflected from the laminae increases in intensity with increase of exposure until the diffusely reflected light disappears; after that for a long range of exposure no change in intensity occurs. This is probably because the individual laminae do not gain in reflecting power after the silver particles have fused together into a reflected surface. This fact makes it possible in photographing spectra with plates not evenly sensitized to secure uniform action throughout the spectrum merely by long exposure.

The greatest spectral purity of the reflected light occurs just before the "saturation" point is reached, dropping slightly for longer exposures and not changing perceptibly till many times the full exposure, when the color tends toward gray and white. From the glass side the purity increases with exposure to a maximum, and then remains constant except with very thin films, in which case the purity again decreases. The cause of this will appear shortly.

EFFECT OF VARYING LENGTH OF DEVELOPMENT

By lowering a plate slowly into the developer different amounts of development were obtained. The only effect of greatly increased development was to cause fog, decreasing somewhat the purity, if the picture was viewed from the film side. Viewed from the glass side

longer development had no effect whatever, except with thin films, when the purity decreased similarly to the effect noted with increasing exposure.

The practice was to develop the plates up to the point where fog began to appear, usually by time development. At temperatures near 20° C. from 45 seconds to a minute gave full development.

ACTION OF THE DEVELOPER ON THE FILM

Using thick films it was found, if development was sufficiently prolonged, that the laminae intersected the gelatine-glass surface, giving a watered-silk effect, the same phenomenon used by Wiener to estimate the thickness of the film. As in film sections heretofore made comparatively few laminae had been found, it has been assumed that but few are formed. The appearance just noted indicated that the laminae might be formed throughout the thickness of the film, provided development were continued long enough.

To study the action of the developer it was decided to section the films and observe them under the microscope. This has been done by Neuhaus, Lehmann, and Cajal. The latter swells the section in water to bring the structure, in its natural size too small to be satisfactorily resolved with the microscope, within reach of average powers. This method was pursued in the present investigation. After development a small oblong of film was cut out with a knife and then stripped from the glass by means of a narrow, straight-edged chisel. The strip of film was then laid on one-half of a split piece of pith. When dry the other half of the pith was laid over it, the whole placed in a microtome and sectioned. On laying the sections on a microscope slip, and wetting with a drop of water, the majority of the laminary structures were easily observable with a one-sixth inch objective. For much of the work where it was not important to have sections of exactly the same thickness, it was found convenient to dispense with the microtome, simply hold the pith in a pair of clothes pins and shave off sections with a razor guided by the forefinger, an operation easily performed after a little practice.

A section of a normally exposed and developed film is shown in Fig. 5 (Plate XIX). It will be observed that the laminae are strongest at the mirror-surface, decreasing in strength with distance from it.

Figs. 6 and 7 (sections of same thickness) show the results of short and long development. With short development the laminae are visible for only a short distance; with long development the laminae are present to a great depth, but a thick band of fog has progressed inward from the surface. The laminae corresponding to the surface ones in the short development are therefore in the long development at a greater depth. From the glass side their effect is precisely similar, unless the film is thin or development has been very long, in which case the fog band reaches to the glass and drowns out the clearly formed laminae. This makes clear the above-noted effects of long exposure and long development as seen from the glass side. A film exposed or developed progressively from edge to edge possesses a layer of well-formed clean laminae running diagonally down from the surface until the glass is reached.

It appears, therefore, that the standing waves are actually formed to a greater depth than has been supposed. To verify this several experiments were performed. A thick film was exposed as usual, then before development wetted and a piece stripped from the glass and so developed from both sides. A section showed the laminae to be formed equally well at both developed surfaces. This is shown in Fig. 8, where 150 distinct laminae may be counted. Another experiment consisted in flowing a plate with a thick solution of celluloid varnish, through which, after drying, the exposure was made as usual. On stripping the varnish coating from the gelatine, developing, and sectioning, laminae were found all through the film. They are, therefore, formed, with monochromatic light, under the conditions of this work, to a much greater depth than the thickest film used.

It follows from these observations that the small effective number of laminae (about 20 or 30 at the most) is due, not to few being formed, as has been assumed, but to the mode of action of the developer. This invited investigation of different modes of development and different developers, from which has resulted a substantial advance in the rendering of pure colors.

Experiments with different modes of development, using the same developer (pyrogallic acid), led to no results. Development with strong developer, with weak slow developer, and with a large proportion of bromide, showed no material difference in the character of

the deposit. Long development followed by application of weak Farmer's reducer was unsuccessful, as the reducing solution simply destroyed everything as it slowly worked through the film.

Attention was then turned to other developers with immediately gratifying results. Ferrous oxalate, glycin, and hydroquinone were tried. All of these developed with great uniformity throughout the depth of the film, without causing fog. Fig. 9 shows a section of film developed with hydroquinone, and should be compared with Fig. 6. Unfortunately, as it seemed at first, the deposit with these developers is black and opaque, making the reflected color dull in the extreme, and the absorption so great that only few of the laminae are effective. To obviate this difficulty the expedient was adopted of bleaching the film with mercuric chloride. This has been done previously by Neuhaus and results in a white, very transparent film. The reflecting power of the bleached deposit is not great, so that luminosity is lost with pyro-developed plates. With plates developed by the three above-mentioned developers this loss of reflecting power is more than compensated for by the greater number of effective laminae. So transparent is the deposit that the absorption is negligible and all the laminae act with practically equal strength. Consequently, instead of the reflected light being a somewhat diffuse band in the spectroscope, it is a narrow bright line. Moreover, increased thickness with consequent greater number of laminae gives increased purity. Practically it was found possible to run the films up to about $\frac{1}{10}$ mm (as determined by the number of laminae in sections) with continued increase of purity. A line source is reproduced by such a film as a brilliant line of about 20 Å. U. width. By transmission a narrow absorption line appears in the spectrum indistinguishable in a small spectroscope from a Fraunhofer line. In Fig. A, IV, V, VI, are shown spectra of the mercury green line as reproduced by films containing approximately 50, 150, and 250 laminae. It will be observed that films of this character might serve for sources of comparatively monochromatic light.

The thickness to which the film may be carried is limited by the thickness of gelatine it is practicable to flow and dry satisfactorily. Greatly increased exposures due to the opacity and slow speed of the thick films made work with them difficult, but the conclusion may be

drawn from this work that the purity of reflected color is, with this procedure, directly dependent on film thickness. It is only a matter of emulsion making and flowing technique to secure films of as high esolving power as one desires.

MIXED COLORS

GENERAL THEORY

Mixed colors, such as two or more spectral lines, or the broad ill-defined bands of the spectrum given by pigment colors, give standing waves which may be compared to the interference fringes they would give in a Michelson interferometer. That is, we have regions in the film where the different wave-lengths acting reinforce regions where they oppose each other. The visibility curves,[1] therefore, are applicable to the structure of the Lippmann film. Fig. 1 gives the resultant

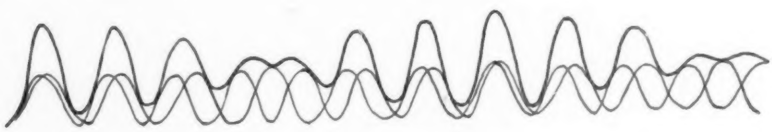

FIG. 1.—Standing Wave System Due to Two Wave-Lengths.

of two wave-lengths, while the visibility curves figured show the manner in which we may expect the laminae to be distributed for various types of incident light. Photographs have been published by Lehmann showing that the resultant structure for two radiations agrees with the calculated. Fig. 12 shows a section of a film exposed to four radiations. The periodic variation in the clearness of the fringes corresponds to the variations of visibility of interferometer fringes.

Two points in connection with the reproduction of mixed colors were studied as of special interest. The first was the question of the degree of complexity of incident light the film is capable of recording. The second was the question of the luminosity values of mixed colors as compared with the component pure ones.

As to the amount of complexity in the incident light which may be reproduced, it is at once apparent that this is dependent on the effective thickness of film. A film developed with pyrogallic acid is, from the previous work, unsuitable where depth is called for, hence the

[1] A. A. Michelson, *Phil. Mag.* (5), **31**, 338, 1891; **34**, 280, 1892.

best results in the way of resolving power were obtained from hydroquinone-developed, bleached films.

Parallel series were carried out on films of the two types. These consisted in exposures to two, three, and four different wave-lengths, and to a broad spectrum band with sharply defined edges.

With pyrogallic-acid developed thick films, the greatest number of separate wave-lengths reproduced was three, and the result was merely a continuous spectrum with three maxima; four radiations produced ill-defined irregularities. The mercury yellow and green lines were well separated with such a film and probably somewhat closer lines would be. A sharp spectrum band of 600 Å. U. width in the green was rendered as a maximum in the green, but all trace of sharp limits was missing, the reproduction being identical with that of the transmission band of a naphthol green-dye solution. This is to be expected, as examination of Fig. 2 shows. The first part of the standing wave-system of the two types of color is identical, and in a thin film, or one whose effective portion is thin, will reproduce as such. The effect of development with pyrogallic acid is in short to reduce all colors to one general type.

With hydroquinone developer and bleaching, two, three, and four radiations were reproduced satisfactorily, except for loss in luminosity, the cause of which will be taken up presently. The spectrum band was reproduced with well-defined edges. From these tests it was concluded, as with monochromatic light, that the capacity of the film to reproduce any form of complex radiation is only limited by the gelatine thickness possible to be obtained practicably.

The second point studied, that of luminosity rendering, will be made clear by some considerations of the theories advanced as to the nature of the reflecting elements in the film. Lippmann developed the theory on the basis of minute reflecting particles distributed through the film. White, for instance, is due to a continuous irregular distribution of such particles. According to this view all the incident light produces reflecting deposit. Schütt[1] advanced the theory that the action of the light is merely to produce a periodic change in the refractive index. Wiener showed that the reflection in the case of bromide of silver plates was from metallic particles. It is possible,

[1] *Annalen der Physik*, **57**, 533, 1896.

for instance, by exposing films of bichromated gelatine, to secure pictures in which the only change produced is in the refractive index.

The luminosities of all but monochromatic pictures will be rendered radically differently according to which mode of reflection takes place. For illustration take white. In the one case we have a large number of reflecting particles, in the other a single reflecting surface, practically the surface of the gelatine. A monochromatic source would give many such surfaces through the film with the structureless deposit and would be far more brilliantly rendered than a white visually as brilliant. Where two or three colors act together there are regions of the film in which, while the total amount of light action is say half the maximum amount, yet sharp changes of intensity are missing. If reflection is due to abrupt change of refractive index these portions would contribute little. A loss of luminosity of the combined with respect to the component colors would result. If this were marked, colors with two or more maxima, such as purple or a subjective yellow, would be weakly reproduced. Lehmann, working with superposed spectra, notes such a loss. The experiments which follow were made with the two kinds of development, and because of the large surfaces exposed, and the manner of exposing, critical examination was easy.

The first experiment was to mix two and three colors (red, yellow, green, and blue, in various combinations) under such conditions that their resultant intensity when acting together could be compared with their intensity separately. The apparatus used consisted of an opaque line screen, opaque spaces twice the width of the transparent, 100 lines to the inch, which was cut in two, and one half turned at right angles to the other. This was placed directly in front of the plate and by means of a screw could be moved any desired distance in the direction of the lines on one half. This motion caused one set of lines to uncover one-third of the surface at a time, the other to continually expose the same strips. In one half would therefore be obtained the three colors superposed, in the other half juxtaposed, in which case the mixing would be visual.

In carrying out this experiment the greatest care had to be taken to avoid the effects of overexposure. As we have seen, exposure beyond a certain point causes no increase of brilliancy. Hence if

each exposure was a full one we would have the entirely covered surface three times as brilliant (with three colors) as the partially covered, indicating a large luminosity loss in the superposed as compared with the juxtaposed. This was avoided by limiting the exposures so that the total exposure with all colors would not reach the saturation point.

The result of the tests was that with pyrogallic acid the loss of luminosity with two colors, as long as exposure was carefully kept below the saturation point, was hardly noticeable, the only effect being a slight tendency of the superposed colors to shift toward shorter wave-lengths. With three radiations a quite perceptible loss of luminosity was observable. In either case exposure beyond the saturation point caused loss of luminosity. With hydroquinone the luminosity loss was much more marked.

The most instructive test was to expose a plate to light of the green-mercury line and to a visual match in color and intensity consisting of a spectrum band of 600 Å. U. width. These gave equal densities in the negative. With hydroquinone development and bleaching the monochromatic side was many times the brilliancy of the other. With pyrogallic acid the two sides were nearly the same luminosity, the complex radiation only slightly less luminous.

Experiments on photographing natural objects whose colors are for the most part continuous spectra with diffuse maxima, besides showing the necessity for a reflecting deposit, emphasized the necessity of this being of high reflecting power. Very fine-grained emulsions proved unsuitable for the reproduction of such colors in their luminosity values, and satisfactory results were obtained only when the silver content of the film was made as large as would still give color. The reason is at once apparent when we observe that the colors under consideration give at most only a few laminae near the surface, as shown in Fig. 2 and in the photographed section, Fig. 13. It is necessary not only that the reflecting power of these be large but that the diffuse deposit behind contribute a share of light in proportion to the light acting to produce it. If the grain is too fine these experiments and work with white light indicate that the separate particles do not act as reflecting surfaces.

The outcome of the experiments is to indicate that with a fairly coarse grain, overexposure being carefully avoided, developed with

pyrogallic acid, there is probably a close approach to the condition of separate reflecting particles. With complex radiation, or with overexposure, there cannot fail to be a certain amount of fusing together and consequent luminosity loss, and in the underexposed parts there is probably also a loss through the formation of deposit not starting

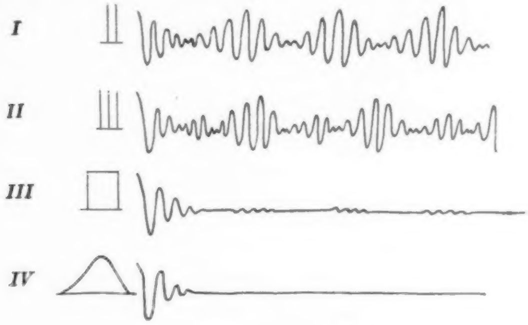

Fig. 2

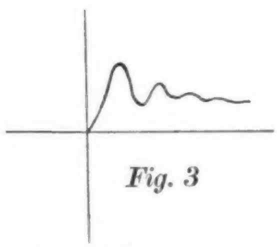

Fig. 3

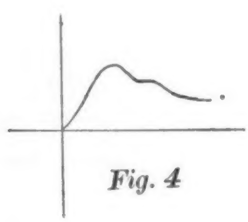

Fig. 4

FIG. 2.—Visibility curves for various sources:

I. Two monochromatic sources.
II. Three monochromatic sources.
III. Spectrum band with sharp limits.
IV. Type of spectrum of light from most natural objects.

FIG. 3.—Standing waves formed by white light from red to blue, as recorded in fine-grain emulsions.

FIG. 4.—Standing waves formed by white light from infra-red to ultra-violet, as recorded by coarse-grained emulsions.

till the light attains a certain intensity. With hydroquinone development and bleaching, the reflection is evidently more nearly of the type caused by changing refractive index.

This at once makes evident that for all photography where luminosity values must be preserved, a developer like pyrogallic acid giving a highly reflecting yet fairly transparent deposit is essential. On the

other hand, where complexity of spectral structure is to be reproduced, a deep-acting developer, which by proper treatment will give a transparent deposit, is desirable.

THE PRODUCTION OF WHITE

On Lippmann's theory, white is produced by reflection from particles of silver thickly and irregularly distributed through the film. Regularly spaced laminae would be entirely absent. Such a deposit would be formed in a perfectly isochromatic emulsion, provided the wave-lengths of the acting light varied between wide limits and the individual silver grains were of appreciable size. If, on the other hand, the acting light varied between rather narrow limits of wave-length, as from red to blue, the size of the silver grains being negligibly small in comparison to the shortest wave-length, a rapidly damped standing vibration of wave-length equal to the mean incident wave-length would result. In Fig. 3 is given the standing wave form due to light from red to blue, in Fig. 4 the form when the incident light is from infra-red to ultra-violet and the silver grain coarse.

Lippmann pictures have been made, exhibiting beautiful whites, yet general difficulty seems to have been experienced. This is partly due probably to the difficulty, with present known sensitizers, of securing isochromatism between wide limits. Several other theories have been proposed and other experimental methods tried to produce white. Lehmann concludes that the greenish appearance sometimes found in whites on short exposure is due to laminae formed in the manner described above. He corrects this by using a screen with three maxima of transmission: red, green, and blue. On short exposure whites will be reproduced as a mixture of these three colors. A serious objection to this method is that colors falling in the minima of transmission will be poorly reproduced.

Cajal from his work concludes that white is due to the formation of a mirror-like surface on the film and that this can be produced only by the use of amidol as an intensifier. The mirror-like appearance presented by the high-lights of Lippmann pictures readily lends itself to the idea that the surface is a silver mirror. That this is possible only when the picture is intensified with amidol is, however, a conclusion unsupported by other experimenters and contradicted by the

undoubted production of white by Neuhaus and others who did not use this intensifier.

The possible modes of production of white are therefore three: first, by a general diffuse deposit as an isochromatic emulsion; second, by forming laminae corresponding to red, green, and blue; third, by producing a mirror surface. The second method was not tried in the present investigation, as being obviously a compromise.

Attention was therefore turned to producing an isochromatic emulsion by combinations of color-screens and sensitizers. Numerous sensitizers were tried; of these much the best was isocol, in that it imparts a sensitiveness free of gaps or maxima. The sensitiveness given by it extends from deep red to blue and violet, gradually increasing toward the latter. Absorbing solutions of wool black, cobalt sulphocyanate, and iron sulphocyanate reduced the action in blue, green, and yellow to that in deep red and gave very satisfactory isochromatic action from red to ultra-violet.

Plates similar to those used in the study of monochromatic colors were prepared and exposed to white, at first with disappointing results. Not only was there practically no light reflected from the partially exposed parts, but the mirror-like high-lights were absolutely black. By intensification with amidol the plates could be made to reflect considerable light. This led to the question whether the intensifier did not merely increase the size of the grain, and whether this might not be done in the emulsion. That the grain was too fine to give whites by diffuse reflection was also indicated by the fact that a fogged plate appeared black and not white by reflection.

A series of emulsions were then made up containing increasing quantities of silver. These were exposed without the mercury mirror and the character of the deposit examined. It was at once apparent that while a very fine grain reflected diffusely very little light indeed, a coarser grain gave a strong white reflection which in the high lights became mirror-like. The brightest whites were given by an emulsion containing four times the silver content of that used for pure color work, or twice that used by Lippmann and others. This emulsion used with the mercury mirror gave perfect white. The theory that diffusely distributed reflecting particles formed in an isochromatic emulsion produce white is therefore supported.

As to the theory of Cajal that white is given only by a mirror-like surface, this was not supported by the results here obtained. The whites were quite perfect in the partially exposed parts. In fact it is the writer's opinion that the formation of the mirror appearance indicates rather the point where the white ceases to be good. A very slight exposure beyond this point, giving the clear yellow by transmission, results in the white becoming black. Everything is in agreement with the view before advanced that the mirror appearance is due to the merging-together of the separate particles with resulting loss in reflecting power. White will be given only so long as the particles are separate, being similar therefore to the white given by powdered glass or other substance transparent in the fused condition.

Since the range of sensitiveness of the emulsion is at best rather limited, and since the grain must be kept small enough to render all colors ordinarily met with, it would not be surprising if some tendency should exist to form laminae corresponding to the mean wave-length, i. e., green. No appearance of green on underexposure of whites was observed. Before mounting the prism the film had an orange tinge which turned to greenish on increasing the angle of incidence. The explanation of this is given by Fig. 4. Although complete laminae corresponding to green light are not formed the deposit of silver increases in density from the surface to the point where the first lamina would form. Rapid damping prevents the formation of more surfaces. There is therefore a slight gap between the surface and the heavy deposit, forming a single thin film. On mounting the prism the upper surface is virtually destroyed. The orange color is what we should expect from Wiener's explanation of the shift of all colors toward red as long as the surface reflection is active.

Sections supported these conclusions. Laminae were absent; in their place appeared a structureless deposit, increasing in strength toward the surface, reaching a maximum a short distance from it, the maximum corresponding to the distance in of the first laminae due to green light, as nearly as could be determined. This appearance is shown in Figure 11.

PHOTOGRAPHY OF NATURAL OBJECTS

To photograph natural objects conditions must be such as to give whites and colors of small spectral purity. This is secured by using

a fairly coarse-grained isochromatic emulsion developed with a developer giving a transparent highly reflecting deposit.

For experiments in this direction a number of different emulsions and modes of preparation were tried. Good results were obtained with very coarse-grained ones, but experience showed the proportions of silver bromide and gelatine in general use to be probably the most satisfactory. Little choice exists between the several modes of preparation published. The silver nitrate may be digested with part of the gelatine; dissolved in water and added, before mixing, to one part of the gelatine; dissolved in water and added to the gelatine containing the potassium bromide; or added in dry powdered form to the latter. The quantity of silver bromide is double that found best for monochromatic light-reproduction.

To secure isochromatism, isocol as a sensitizer, with the absorbing solutions above given, or, as the sensitiveness imparted by isocol is very fugitive, a more permanent combination of pinacyanol and pinaverdol, with a screen of wool black, was found to answer fairly well.

The only point in the manipulation not yet described is the choice of film thickness. The standing wave-structure being shallow, great thickness is no object. Speed, too, is gained by small depth. The thinnest film is obtained by flowing the warm emulsion on and off glass plates warmed to the same temperature. This gives a thickness of about $\frac{1}{400}$ mm, on which most colors reproduce satisfactorily as far as the eye can tell. The resolving power is small of course, and some anomalous results are to be expected. Purple is about the only color of any complexity often met with, and the film should be thick enough to resolve its two maxima well. The most satisfactory thickness was obtained by flowing the emulsion on and off glass plates at room temperature, about $\frac{1}{200}$ mm. Exposures with $f/3.6$ on sunlit objects ranged from $1\frac{1}{2}$ to 5 minutes according to sensitizers, etc.

With emulsions made up and used in this way good color rendering was obtained. The sum total of the results on photographing natural objects has been to vindicate the procedure indicated by theory and carried out by Lippmann. The deviations from that procedure by Lehmann and Cajal seem unnecessary to secure successful results.

The difficulties noted by all workers with the process as applied

PLATE XIX

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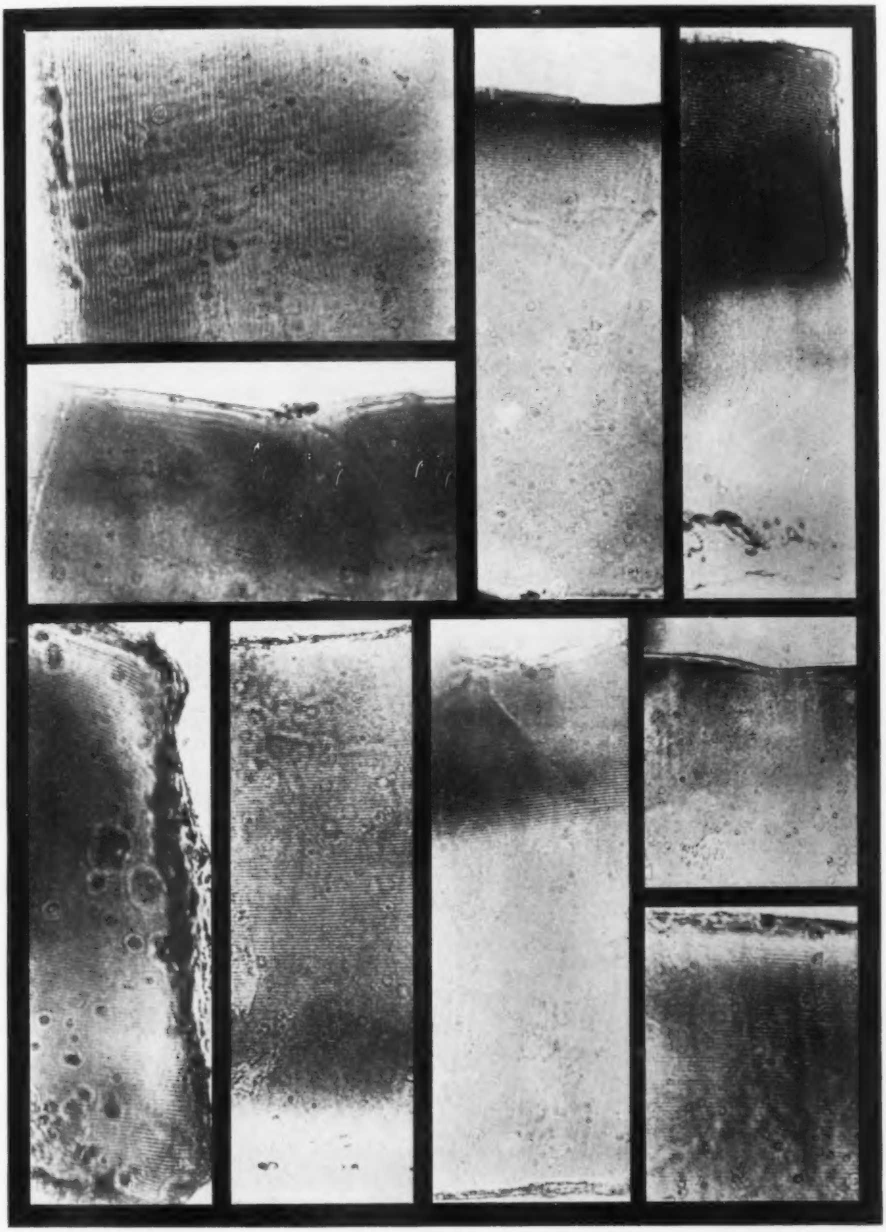


11

8 9 10 12

5. Section of film exposed to λ 5461, developed with pyrogallic acid.
6. Film developed one minute with pyrogallic acid.
7. Film developed 15 minutes with pyrogallic acid.
8. Film stripped and developed from both sides.
9. Film developed with hydroquinone.
10. Bathed plate.
11. White (short exposure).
12. Four wave lengths: λ 6430, 5780, 5461, 5086.
13. Heterogeneous green light; napthol-green color-screen.

to photographing natural objects were found to be very real. They are in brief the great dependence of success on correct exposure and development. Very slight deviations will make the colors either weak or diluted with white. This is due to the laminae being few and close to the surface. With pure colors a certain amount of clogging up affects but a small part of all the laminae, in diluted colors practically all. A larger proportion (twice as much) of bromide in the developer than was used for pure colors was found materially to help the brilliancy of these colors. A larger percentage of failures is to be expected in any process of color photography than with black and white, since the eye is more sensitive to errors of treatment where color occurs. The sensitiveness of the Lippmann process to slight deviations from correct conditions is, however, much greater than the three-color method, and good results come only from repeated patient trials. When obtained they are extremely dependent on correct viewing conditions, to appear to any advantage. The colors being formed for the most part by two or three laminae backed up by a diffuse deposit, great care must be taken to exclude all light except that coming in the direction to be regularly reflected by the laminae. Light from other directions is not sent to the eye by the laminae but is by the diffuse deposit, causing a drowning-out of the colors with white light. By making the film excessively thin so that the laminae are formed, but not the deposit behind, the colors are more brilliant and less affected by conditions of illumination. Colors of any complexity, such as purple, however, suffer.

A SUBSTITUTE FOR THE MERCURY MIRROR

One of the obstacles to wide use of the Lippmann process is the necessity for a mercury mirrror. Each plate-holder must be arranged as a tank into which before exposure mercury must be flowed. Several attempts have been made to obtain substitutes for the mercury. Krone[1] dispensed with it altogether, relying on the gelatine-air reflection, but the colors are then dull and unsatisfactory. Lehmann has flowed the emulsion on a collodion-coated polished metal plate. After exposure the composite film could be stripped and placed on a glass plate. Pure colors, spectra, etc., can be so reproduced, but those

[1] *Darstellung der natürlichen Farben durch Photographie*, 1894.

whose lamina system is close to the surface cannot, since that space is occupied by the collodion. Placing a silver mirror in close contact with the gelatine has the same objection.

The writer has recently discovered a substitute for the mercury mirror, of a form which permits the plates to be handled and used precisely as ordinary dry plates.

The procedure is as follows: A glass plate is heavily silvered and then flowed with a thick solution of celluloid in amyl-acetate. When this varnish is dry the plate is placed under water; this slowly works under the coating of celluloid, lifting it from the glass, and *bringing with it the silver.* This flexible silver mirror is immediately laid, silver surface down, on a wet Lippmann plate and allowed to dry there, a necessarily somewhat slow process. When dry, the gelatine film has the silver surface in optical contact with it. The plate may be then exposed at any time in an ordinary plate-holder. After exposure the celluloid film is stripped from the gelatine, taking with it most of the silver, the plate developed, and after thorough washing, the remains of the silver are removed with a tuft of wet cotton.

This substitute works perfectly for all types of colors, and except in the laboratory where a convenient dark room makes the use of the mercury mirror simple, facilitates the practical working of the process. Especially would it do so for the photographer who buys his plates ready made. In that case the only difference between ordinary and color photography would be the longer exposure in the latter case, and the necessary mounting of a prism on the picture, and of course the impossibility of copying.

A difficulty which has proved rather troublesome is that some of the best sensitizers are apt to lose their effect during the slow drying. Erythrosine acts perfectly; pinacyanol and pinaverdol are apt to fail. This can probably be overcome, either by different choice of sensitizers, by so treating these that slow drying does not harm, or perhaps by finding some more porous substance than celluloid which, acting the same in other respects, will permit quick drying. Collodion has been tried, but has not been found to strip off the gelatine well.

THREE-COLOR INTERFERENCE PICTURES

The capacity of the Lippmann film to reproduce pure spectrum colors easily and with certainty adapts it for an application to the

three-color process, published by the writer some time ago.[1] In the synthesis of the properly taken records of the three-color sensations spectrally pure red, green, and blue light are called for. The Lippmann film furnishes an unequaled means for securing these.

The method used was to place before the plate an opaque-line screen, having opaque spaces twice the width of the transparent. The three positive color records were projected one after the other with their appropriate colored lights, the line screen being moved each time the width of a clear space. The result was similar to the Joly picture, consisting of alternating lines of red, green, and blue.

In the first pictures so made the colored lights were obtained from sunlight by a monochromatic illuminator, but satisfactory purity and shortness of exposure were not secured. In experiments since carried out the line screen was removed from contact with the plate, as this necessitated a narrow source of light, and placed in contact with the three-color positive, an image of the screen and positive being formed by a Planar lens of fine defining power. For light-sources the cadmium red line (λ 6439), the magnesium green (λ5170), and the lithium blue (λ 4602) were found most available, obtained in the manner described in a following section.

The three-color interference pictures so made are of great brilliancy and beauty, especially if the hydroquinone development and bleaching are used, when the component colors are of practically ideal purity. Quite long exposures are necessary, amounting under the best conditions to a total of fifteen or twenty minutes. This time can probably be materially reduced. The pictures are, however, far more easy and certain besides being more brilliant than the regular Lippmann picture. They constitute an excellent means of carrying out the three-color principle, and have the interesting property of owing their color to the direct action of light and not to pigments or colored glasses as do the other three-color schemes. They can, besides, be duplicated indefinitely.

SENSITIZERS

During the progress of the work various color sensitizers were used, depending on the portion of the spectrum photographed. The list included erythrosine, cyanin, pinacyanol, pinaverdol, pinachrome,

[1] *Physical Review*, **24**, 103, 1907.

isocol, homocol, and dicyanin. For bathing $\frac{1}{100000}$ solutions in water were used, without ammonia; in the emulsion about one cc of a $\frac{1}{1000}$ alcoholic solution to 100 cc of emulsion. Some observations of their behavior with these very slow emulsions are of interest.

In general it was found that bathed plates acted more cleanly and brilliantly, two sensitizers, isocol and homocol, acting very poorly in the emulsion. Ammonia was not used as it has a tendency to make the plates ripen, with consequent great increase in the grain. Bathed plates were, however, unsuitable for a large part of the work, since the sensitizing action extends only a short distance into the film, even with long bathing. Fig. 10 shows a section of a plate bathed fifteen minutes in a $\frac{1}{100000}$ solution of homocol.

For green all of the sensitizers are good except cyanin, dicyanin, and pinacyanol. For the red, pinacyanol is far and away the best, the action of cyanin not extending far enough down, and that of dicyanin being too feeble. The great difficulty has been to sensitize for the light blue. On ordinary plates there is apt with many sensitizers to be a minimum in the blue green near λ 5000. On these slow plates this gap is in the blue. This is owing to the natural sensitiveness of the plates only extending to the violet, while with fast plates it goes down to the blue. The descending curve of green sensitiveness imparted say by erythrosine meets the descending curve of the emulsions' own sensitiveness in the one case in the blue, in the other in the blue green. This was verified by greatly reducing the amount of sensitizer when the weak blue sensitiveness was stronger than the imparted sensitiveness in the blue green. This behavior of the plates makes sensitizer combinations, such as pinacyanol, homocol, and pinaverdol,[1] which fill the blue green in ordinary plates, inefficient here. A blue sensitizer, not needed for fast plates, is really required with the Lippmann plates. Isocol was the only sensitizer found which gave a sensitiveness free from gaps.[2]

As to the keeping qualities of the sensitized plates, it was found that the erythrosine-cyanin, or erythrosine-pinacyanol emulsion plates kept

[1] R. J. Wallace, *Astrophysical Journal*, **26**, 299, 1907.

[2] The sensitizers used were of the following makes or sources: pinacyanol, pinaverdol, pinachrome, dicyanin, from Meister, Lucius, and Brüning; isocol, homocol, from the Bayer Co.; cyanin from Eimer & Amend, New York; erythrosine, from F. A. Reichardt, New York.

well, at least for a week or two. Bathed plates lost their sensitiveness quite rapidly; isocol-bathed plates in four or five hours, rendering them useful only for quickly carried out experiments. Pinaverdol in the emulsion in one case lost its action in four days. Pinacyanol and pinaverdol emulsions which dried slowly, as those prepared for use with the silver-celluloid mirror, sometimes showed complete loss of color-sensitiveness.

SOURCES OF MONOCHROMATIC LIGHT

In the study of monochromatic light reproduction and in making three-color interference pictures difficulty was experienced in finding suitable monochromatic sources. As the plates are very slow, and large surfaces were illuminated, sources capable of giving a large quantity of light for a long period were essential. Many ordinarily used sources were useless, either because of their small intrinsic brilliancy, or because of their too short life. The spark, the vacuum tube, the flame, arcs between easily melted metals, were among these. Another requisite was that the line used should not be so near other lines as to render its separation impossible by means of absorbing screens; resolution by means of a prism causing too much loss of light.

The following list of the most satisfactory sources found is given as of possible use in other lines of work where great intensity for a long period is required. It is by no means complete, since search was stopped when a satisfactory one for any color was found. Where obtainable the best sources are undoubtedly the Heraeus fused quartz lamps and the mercury vacuum arc. The open arcs here tested are as a rule more brilliant and are easily manipulated. Carbon was used uniformly as negative electrode:

Red. Lithium λ 6708. Lithium sulphate in cored carbon.

Cadmium λ 6439. Cadmium ordinarily burns with dense brown fumes which form a cake of brown oxide around the rapidly melting electrode. This may be avoided by melting the cadmium into a copper tube. The copper and cadmium lines appear together, but the red cadmium line is distant from the copper lines. A current of not more than four amperes is best.

Orange. Lithium λ 6103. Lithium sulphate in cored carbon.

Yellow. Sodium λ 5893. Sodium chloride in cored carbon.

Green. Thallium λ 5360. Metallic thallium in cored carbon.

Magnesium λ 5162. Magnesium powder in cored carbon.
5172
5167

Silver λ 5460 and 5209. Silver, which in rods melts in a few seconds, burns steadily and brilliantly if a thick wire is placed in a cored carbon. Wire of 2 mm diameter in a carbon of 10 mm diameter gave excellent results.

Cadmium λ 5085, obtained from an alloy of tin and cadmium in a cored carbon, one part by weight of cadmium to six of tin.

Blue. Lithium λ 4602. Lithium sulphate in cored carbon.

Solutions of various aniline dyes separated most of these clearly. Copper chloride was found useful when either end of the spectrum was to be absorbed. With increasing concentration its absorption moves in, maintaining constantly a sharp boundary. Care must be taken that the temperature of the solution does not rise while in use as this causes widening of the absorption.

MISCELLANEOUS PHENOMENA

Relative position of reproduced with reference to incident wave-lengths.—Owing to the partial solubility of the gelatine and perhaps the washing-out of unaffected silver bromide the films show a general tendency to shrink in development and washing. This causes the colors to shift toward blue. This tendency is much more marked when the plates are fixed with "hypo." In most of the work fixing was dispensed with, Lehmann having found the pictures to keep perfectly without. This shift is much more marked with pure colors than with mixed, the interlaminary spaces being freer of deposit. This is well shown by photographing a continuous spectrum, using a rather wide slit, beside a line spectrum; the lines are reproduced as noticeably of shorter wave-length tint. If the slit is then closed up to extreme narrowness and exposure is made, the spectrum colors agree in tint with the monochromatic lines.

Bleaching with mercuric chloride, on the other hand, swells the film; the two processes of fixing and bleaching therefore tend to neutralize each other.

In working with very thick films a spurious "Doppler effect"

frequently occurs. The surface portions of the film wash away more than the deeper, so that a diffuse band of light appears on the blue side of the sharp line.

Characteristic curve.—In the photographic plate the density by transmission varies nearly directly with the time of exposure. This is because the deposit of silver is in logarithmic relation to the time of exposure, and the increase of opacity of an absorbing medium also follows such a law. When the deposit is viewed by reflection this relationship between exposure and intensity does not hold, the relation becomes logarithmic instead of linear. The exact relationship is complicated by absorption, which tends to hasten the "saturation point." A further complication arises in the Lippmann process with very short exposures, owing to the necessity for the reflecting particles to have a certain size and a certain closeness to each other to form a regularly reflecting surface. This was observed in a plate one-half of which was exposed behind a coarse opaque grating with lines covering $\frac{2}{3}$ of the surface. The part behind the grating was exposed to nearly full exposure, the part not covered exposed until, when held at arm's length (where the lines were no longer visible), the two parts appeared of exactly the same density. By reflection the portion only partly covered by the full exposure was much more brilliant than the portion completely covered by the shorter exposure.

These several effects tend to shorten the scale of gradation of the plate, unfortunately, because the eye is more sensitive to this defect in colored than monochromatic pictures.

Different rates of development for different colors.—In developing three-color negatives where all three images are on one plate it has been observed that the three images develop at different rates although the exposures and the final densities are correctly proportioned. The Lippmann film exhibits the effect clearly. In making three-color interference pictures the colors were found to depend considerably on the time of development. With short development the green and blue predominated, with longer the red became stronger, the final picture showing, however, the relative exposures not too long for blue and green. Trouble from this effect was easily avoided by keeping the time of development constant and regulating the exposures for that development.

SUMMARY OF RESULTS AND CONCLUSIONS

Reproduction of monochromatic light.—A smaller amount of silver bromide than usually employed gives purer reflected light from the Lippmann film.

Increase in thickness beyond about $\frac{1}{200}$ mm causes no corresponding increase of purity so long as pyrogallic acid development is used.

The standing waves are formed throughout the thickness of the film; non-formation of laminae is due to surface action of the developer.

Other developers such as hydroquinone develop evenly through the film. By bleaching the deposit formed by their use films are obtained giving purer reflected colors than heretofore obtained and increasing in resolving power with thickness.

Mixed colors.—Films developed with pyrogallic acid have small capacity for rendering complex structure, but luminosity values are well preserved if the grain is not too fine or exposure too long.

With hydroquinone and bleaching, complex radiations are produced with a fidelity dependent only on the practically attainable thickness of film. This resolving power is at the cost of luminosity.

White.—White is produced by the action of white light on fairly coarse-grained rigidly isochromatic emulsions.

Natural objects.—The colors of natural objects are well reproduced by emulsions suitable for giving whites and mixed colors, i. e., of somewhat coarser grain than is best for pure colors.

Pictures of natural objects are more difficult to obtain than those of pure colors because of shallowness of the standing wave-structure.

Substitute for the mercury mirror.—A means has been found of affixing a silver reflecting surface in optical contact with the film, enabling the mercury mirror to be dispensed with.

Three-color interference pictures.—The Lippmann film, by reason of its capacity for reproducing pure colors, is well adapted to application to three-color photography.

In conclusion I wish to acknowledge my indebtedness to my father, Mr. Frederic E. Ives, whose life-long experience with photographic processes has always been freely placed at my service. I also wish to thank Professor J. S. Ames for the kindly interest he has shown in the progress of the work.

JOHNS HOPKINS UNIVERSITY
March 1908

THE PRODUCTION OF SPECTRA BY AN ELECTRICAL RESISTANCE FURNACE IN HYDROGEN ATMOSPHERE

By ARTHUR S. KING

The purpose of this paper is to give the results of a series of experiments in which spectra were obtained by means of a tube-resistance furnace in an atmosphere of hydrogen. Briefly stated, the method was to pass a heavy alternating current through a graphite tube placed in an air-tight chamber filled with pure hydrogen, thus heating the tube to incandescence and vaporizing the metal or salt placed therein. The distinctive points of the method are twofold: (1) the elimination of the electrical action given when the incandescent vapor carries the electric current, as in the arc and spark; (2) the avoidance of the chemical action of unknown character and magnitude which takes place in the flame. We have thus to deal with a spectrum given at a temperature which may be regulated by the strength of the heating current, with no supply of oxygen present, and when the possible chemical action is very limited.

The investigation was directed along two lines: (1) to see whether the spectra of certain elements could be obtained under conditions approaching so nearly to a "temperature spectrum" as we have here and what conditions modified the spectrum; (2) to make a more intensive study of certain spectra for which a considerable number of lines were obtained, comparing the lines and their relative intensities with those given by other light-sources.

Apparatus.—The chamber to contain the resistance tube was a brass cylinder of 10 cm internal diameter and 40 cm length, with an extension tube at one end closed by a window, while the other end of the cylinder was closed by a cap clamped on and fitting tightly with a rubber washer. This cap could easily be removed and had a short extension tube coaxial with the main cylinder, closed by a window. The graphite resistance tube was supported in the middle of the cylinder, its axis being in a line with the window tubes, so that the interior of the incandescent graphite tube could be observed

from either end. The support of one end of the furnace tube made contact directly with the side of the brass chamber, while the support of the other end was insulated and connected with a heavy copper terminal passing out through an insulated joint in the side of the cylinder. The heavy current leads were joined, one to the insulated electrode, the other to the side of the brass cylinder itself. Two inlet tubes, one joined to a vacuum pump, the other through purifying vessels to a hydrogen generator, completed the essential parts of the furnace chamber.

For the resistance tubes both carbon and Acheson graphite were used, the latter being more easily machined and making better contact with the terminals, though the necessity for thinner walls made them more fragile than the carbon tubes. The length of the tubes used was 15 to 20 cm, and they were bored out with a hole 4 mm in diameter. The original outside diameter of 16 mm was left for a length of about 15 mm at each end for the contact and the wall filed down between these points to a thinness sufficient to give the necessary resistance, this requiring a wall only about 0.5 mm thick for the graphite tubes with the available power. The heating current was supplied by a 5 K. W. transformer kindly loaned by Professor Cottrell of the Department of Physical Chemistry. This transformer could be connected for different voltages in the secondary, the connection generally used giving about 25 volts when supplied from the 110-volt circuit. The primary current in the transformer was regulated by a rheostat, enabling the heating current to be gradually raised to the maximum output.

The hydrogen used to fill the chamber was generated from zinc and sulphuric acid, and purified by passing through a series of vessels containing sulphuric acid, alkaline pyrogallic acid, and sodium hydroxide.

The photographic observations were made with a small quartz spectrograph, Seed's orthochromatic plates being used. A quartz lens was employed to project an image of the interior of the furnace tube on the slit.

Method of work.—If the substance to be placed in the tube absorbed water readily, all water was first driven off by heating in a porcelain crucible. Then the substance was transferred to the tube which was

kept heated by the current almost to red heat. The chamber was closed as quickly as possible and pumped out to a pressure below 1 cm, sometimes as low as 1 mm. Hydrogen was then passed slowly in and pumped out, the chamber being flushed out several times with the gas and finally allowed to stand full of hydrogen at atmospheric pressure. The heating current was then turned on and the primary resistance gradually decreased until the full voltage of the transformer was on the tube, and the exposure made, a current of nearly 200 amperes then passing through the tube. As the pressure of the hydrogen increased with the heating of the tube, a stopcock connecting with the water-jet pump through sulphuric acid vessels was opened from time to time keeping the hydrogen in the chamber always somewhat above atmospheric pressure.

When the fragile graphite tubes were used, the current was usually allowed to run until the tube broke, this taking place, in cases where there was no vigorous action between the substance being vaporized and the material of the tube, after a run of 15 to 30 minutes, owing to stresses caused by the unequal expansion of the tube and the supports by which the current was led in. The window at the opposite end from that toward the spectrograph could be used at any time for visual observations by placing a direct-vision spectroscope in front of this window. This was especially useful for watching the change in the spectra at different stages of the run.

RESULTS

Sodium.—The observations made with sodium in the tube gave important data both on the part played by chemical action and on the lines given under the conditions present in the furnace. Only visual observations were possible with metallic sodium in the tube, as the tube disintegrated so rapidly under the action of the sodium that no time for a photographic exposure was allowed after the furnace reached maximum heat. With the limited chemical action here present, the D lines did not appear readily, in spite of the large amount of sodium vapor in the tube. They appeared, however, as only moderately strong bright lines when the tube reached brightest incandescence.

With carefully dried sodium chloride in the furnace, the action on

the material of the tube was much slower and it was possible to photograph the spectrum. A preliminary visual observation showed that the chloride gave the D lines under these conditions better than the pure metal. The lines appeared readily as the tube became hot and remained as strong bright lines.

A photograph was obtained with sodium chloride in the tube which confirmed the visual observations as to the strength of the D lines given by the salt and showed a number of other sodium lines whose identification in the visual observations was rendered uncertain by the small dispersion used. The following pairs of lines appear on the plates. The intensity numbers indicate roughly the intensities of the pairs, the component lines being so close together as to render difficult a judgment of their separate intensities.

λ	Intensity	λ	Intensity
6161.15 / 6154.62	6	4669.4 / 4665.2	trace
5896.16 / 5890.19	60	3303.07 / 3302.47	16
5688.26 / 5682.90	8	2852.91	4
4983.53 / 4979.30	2		

Two interesting points may be noted for this spectrum: (1) Three members of the principal series, viz., $\lambda\lambda$ 5896–90, 3303–02, 2853, are given very strong under conditions which *exclude the presence of any appreciable supply of oxygen.* This contradicts the view held by some investigators that these lines require the presence of oxygen; although, as has been noted, it is probably true that chemical action, such as that afforded by the dissociation of a sodium salt, greatly favors the production of these lines. (2) A comparison of this list of lines with that given by de Watteville[1] of flame lines of sodium shows that he obtained with the flame the lines listed above (except the pair $\lambda\lambda$ 6162–55, out of the range of his photographs) and no others, in spite of the vigorous chemical action taking place in the flame. Furthermore, the relative intensities of the pairs as given by the furnace are surprisingly close to those of de Watteville's plates, the

[1] *Phil. Trans.*, **204**, 139–168, 1904.

latter giving intensities 50, 8, 4, 2, 10, 5, for the six pairs beginning with λ 5896. He found these lines of about the same intensity in both the cone and the outer portion of the flame used.

Calcium; line spectrum.—The following calcium lines were photographed distinctly with metallic calcium in the furnace tube in an atmosphere of pure hydrogen:

5594.64	4435.86
5588.96	4425.61
5270.45	4226.91
4456.08	

Of these lines, λ 4227 was very broadly reversed. Traces could be detected of the group of six lines from λ 4319 to λ 4283. Nothing was to be seen of λλ 3968, 3933 (H and K of the solar spectrum) which are strong in arc, spark, and sun.

A remarkable phenomenon is to be noted in regard to the lines H and K. Although they did not appear with this large amount of pure calcium present, they were given faintly on two plates when calcium (probably some compound) was present only as an impurity. One of these plates was taken with caesium chloride in the furnace tube, the other with mercuric chloride. In both cases λ 4227 is given strong but not reversed, and the H and K lines may be seen distinctly, coinciding exactly with the same lines in comparison arc spectra.

Although this behavior of H and K requires further investigation before an explanation can be offered, it may be mentioned here that the lines appear faintly in the more intense flames and traces of them were obtained by the author in a previous investigation,[1] when calcium was vaporized in a carbon tube heated by an arc on the outside, air being present. It thus appears that the temperature of the furnace will not give these lines unless some chemical action takes place which is not permitted when pure calcium is vaporized in an atmosphere of hydrogen. Aside from the absence of the H and K the furnace in hydrogen gives a spectrum not very different as regards the lines which appear and their relative intensities from the flame spectrum observed by de Watteville[2] and by Olmsted[3] and that of the arc furnace in air.

[1] *Astrophysical Journal*, **21**, 236–257, 1905.

[2] *Loc. cit.*, p. 152. [3] *Bonner Dissertation*, 1906.

Band spectrum.—Bands were photographed in the orange, yellow, and green which appear to coincide in position with the flame bands at λλ 5934, 5816, and 5543, ascribed by Eder and Valenta[1] to the chloride and oxide. As these compounds were absent in the furnace, the bands which appear must belong to the metal itself or to the carbide or hydride. A rich band spectrum was also observed visually in the red, for the definite location of which a higher dispersion will be necessary.

Iron.—A large number of iron lines were given by the metal in the furnace tube. This was probably as near a "temperature spectrum" as any that were obtained in the hydrogen atmosphere, there being no perceptible chemical action on the iron unless a slight adhesion to the graphite of the molten iron which was not vaporized indicated the formation of a carbide.

On account of this minimum chemical action, it is of interest to compare the list of lines given by the furnace with those obtained by de Watteville[2] from the iron flame, the temperatures of the two sources being not very different, while in the flame the chemical processes have full scope. The following table gives the estimated intensities of the iron lines on my plates, and in the next two columns the intensities given by de Watteville of the same lines as they appeared respectively in the cone and exterior portion of the flame used by him.

The following table permits only a very rough comparison between the spectra of the furnace and flame, as the photographs were made by different observers under widely different experimental conditions. Many more lines are recorded by de Watteville than are given on my plates, but this does not give a comparison of the actual richness of the two spectra, as the furnace tube usually broke after a run of 20 to 30 minutes, while exposures as long as eight hours were used by de Watteville for the flame. In general, however, the results speak strongly for the spectrum of the flame being due very largely to temperature radiation, since the lines given by the furnace in hydrogen are found not only in the cone of the flame, but in the large majority of cases in the external layers where chemical action should be at a maximum. There are, to be sure, many differences in rela-

[1] *Beiträge zur Photochemie und Spectralanalyse*, p. 92.

[2] *Loc. cit.*, pp. 164–168.

λ	Furnace in Hydrogen	Flame Spectrum (de Watteville)	
		Cone	Flame
5434.66	8	2	..
5429.74	8	1	..
5397.27	6	2	..
5371.62	5	4	3
5328.15	10	5	4
5270.43 } 5269.65 }	10	6	5
5167.50	4	1	..
4528.78	9	3	..
4443.30 } 4442.46 }	4	2	..
4427.44	6	8	6
4415.27	7	7	1
4404.88	8	9	4
4383.70	15	10	6
4325.92	7	9	5
4307.96	8	8	5
4271.93 } 4271.30 }	1	8	6
4260.64	7	7	1
4250.93 } 4250.28 }	2	5	2
4222.32	1	3	..
4219.47	2	2	..
4134.77	1	4	..
4132.96	1	1	..
4067.36 } 4067.04 }	2	2	..
4063.63	3	10	5
4058.30	4	1	..
4045.90	20	15	7
3969.34	1	8	trace
3923.00	10	10	10
3920.36	9	10	10
3899.80	2	9	9
3895.75	6	9	9
3886.38	10	12	12
3878.82 } 3878.12 }	8	10	10
3860.03 } 3859.34 }	18	10	10
3841.19 } 3840.58 }	2	7	3
3827.96	10	7	2
3763.90	2	6	3
3758.36	2	7	4
3749.61	12	8	4
3737.27	12	8	8
3720.07	10	8	8
3705.70	4	8	8
3687.58	1	6	3
3647.99	1	7	5

λ	Furnace in Hydrogen	Flame Spectrum (de Watteville)	
		Cone	Flame
3631.62	1	8	5
3618.92	1	8	5
3608.99	1	8	5
3581.32	2	8	8
3570.23	2	9	7
3497.92	1	7	6
3490.65	1	8	8
3476.75	1	7	7
3475.52	1	8	8
3465.95	1	8	8
3441.07 } 3440.69 }	5	10	10

tive intensity of lines, which may be due both to the differences in temperature and to the chemical processes in the flame.

At the Mount Wilson Solar Observatory I have had an opportunity to compare these results for the iron spectrum with the intensities of iron lines in the spectra of the sun and of sun-spots. The lines given strongly by the furnace in the yellow and green are without exception lines much intensified in sun-spots. This relation does not hold so generally for lines in the violet and the beginning of the blue, a condition found by Messrs. Hale, Adams and Gale[1] to hold for other light-sources in which the temperature was comparatively low. As furnace spectra with more efficient apparatus and higher dispersion will probably soon be obtained in the observatory laboratory, it will perhaps not be profitable in this paper to go farther into the astrophysical side.

Copper.—With the metal in the furnace, the only copper line obtained was the flame line λ 5105.75. The same groups of bands appear which were observed by the author with the arc furnace and which have also been obtained in the flame. These bands have heads at λλ 4005, 4280, 4499, 4547, 4598, 4649, 4689. With the tube furnace in hydrogen, the formation of either a carbide or hydride is possible, but the first of these compounds is unlikely in the oxyhydrogen flame, and the second could scarcely appear in the arc

[1] *Contributions from the Solar Observatory*, No. 11; *Astrophysical Journal*, **24**, 185–213, 1906.

furnace without hydrogen atmosphere. It thus seems probable that these copper bands are due to the metal itself.

Mercury.—Several attempts were made to obtain the mercury spectrum by forcing the furnace to its maximum temperature, but no lines were obtained. Observers of the flame spectrum have had the same experience. Mercury placed in the furnace tube was of course quickly vaporized and might not be sufficient for the purpose, so a large supply of the vapor was provided by placing a crucible of the liquid immediately beneath the furnace tube. A good deal was also lying on the bottom of the brass chamber. The furnace was then given a long run at maximum current. The furnace chamber around the tube became hot enough to melt lead on the outside, and the mercury was vaporized in large quantities, condensing thickly over all parts of the interior when the apparatus cooled. The furnace thus ran in an atmosphere of mercury vapor saturated at a high temperature, but no spectrum appeared.

Mercuric chloride was tried in the hydrogen atmosphere. It was thought at one time that the green mercury line was observed visually, but the low dispersion made this uncertain and it was not confirmed by the photographs.

Caesium.—The chloride was used in the furnace tube, but the conditions were not so favorable as in the author's former work with the arc furnace, only the pair $\lambda\lambda$ 4593, 4555 appearing faintly on the plates. Probably the small amount of the salt in the tube would account for this weakness of the spectrum, as with the arc furnace a large quantity of the chloride was fed into the tube as the experiment progressed.

As has been noted, this spectrum as well as that of mercuric chloride was notable in that it showed the H and K lines of calcium.

SUMMARY

The results of this investigation may be summarized briefly under two heads: (1) There is no evidence to indicate that a sufficiently high temperature will not produce radiation without the intervention of either electrical or chemical action, although when chemical action was permitted the radiation appeared to be favored thereby; (2) the similarity of the furnace spectra to those given by

the more intense flames indicates that the radiation of the flame is very largely a thermal effect, aided without doubt by the abundant chemical processes attending the combustion.

These experiments were carried out in the physical laboratory of the University of California, and I wish to express my thanks to Professors Slate and Lewis for the facilities placed at my disposal.

PASADENA, CAL.
March 1908

SOME REMARKS ON PROFESSOR BARNARD'S ARTICLE ON *SATURN'S* RINGS

By W. H. WRIGHT

In the January number of the *Astrophysical Journal* Professor Barnard has published an exceedingly interesting account of his observations of *Saturn's* rings during the recent opposition. He has also added an explanation of the bright "beads" or "knots" observed on the rings when we view their unilluminated surfaces. At the time of reading Dr. Barnard's article I had in the process of preparation for publication some notes on the same subject, that is, in explanation of these phenomena, the theory, like that of Barnard's, being based, partly at least, on the meteoric constitution of the rings. So far as I am aware Professor Barnard's paper contains the first published discussion of the phenomena presented by the "disappearance" of the rings, treated in the light of our knowledge of their meteoric constitution, it being a curious fact that even recent discussions of the subject have been based upon the assumption that the rings are opaque. My conclusions differ in some respects, however, from those of Barnard, and it appears worth while to make some statement of them; but as much that I had in mind to say has been said by him, I shall, to avoid repetition, put my remarks in the form of comments on his article.

Professor Barnard states that since the rings are made up of meteorites we should expect that they would be visible from the unilluminated side by the "percolation, scattering, and reflection of sunlight through them," and on this ground he endeavors to explain the visibility, not only of the crape ring, but of the entire system, including the outer beads. To quote directly from the article:

> We should therefore expect to see the entire surface of the rings at this time by percolation, scattering, and reflection of the sunlight through them. One might expect under these conditions that the brighter portions of the ring wouldappear dark when so seen by cutting out more of the sunlight through a greater number of particles. This, however, up to a certain point of density would not be so; it would in reality be just the reverse. In the case of the crape ring it would appear faint—as it does always—because of the fewer particles to reflect the sun-

light. Were they more densely packed, as in the bright rings, there would be a relatively greater amount of scattering, reflection, and diffusion of the light and they would appear relatively bright.

It is apparent to any observer of *Saturn* ordinarily, with a telescope of sufficient power, that the outer one-fourth of the inner bright ring is much the brightest part of the entire ring and ball system; the inner portion of that ring being of the same brightness as the outer ring, which is uniformly illuminated. Let us therefore see where these condensations fall on the projection of the rings.

As regards the visibility of the crape ring it seems to me that Professor Barnard's statement is correct. In fact he might have gone farther and said that the crape ring would appear intrinsically brighter viewed from the unilluminated side at a low angle with the surface than it does when seen from the relatively high angle at which it is observable from the other side. It seems not improbable that when viewed at a grazing angle its intrinsic brightness is, in places, probably half that of the brightest part of the system. This increased brightness is due to the fact that the lower the angle of observation the more meteorites, of which the ring is composed, are included in a given small solid angle of vision, and therefore, up to a certain point, the brighter the thin projection of the ring should appear.

Considering now the visibility of the denser part of the ring system from the unilluminated side, due to light coming through it, the explanation seems to me to be at least doubtful; while it appears very improbable that any illumination as strong as that involved in the outer beads could be due to this cause. Let us assume that the ring system is solid. In that case we, on the unilluminated side, would get no light except that coming from the edges. If we now conceive the ring to be composed of closely packed, independent bodies, we shall still get no light, provided the bodies are close enough together. If a number of these bodies, or meteorites are removed, here and there, through the mass, some of the remaining ones will finally be seen illuminated, and as the process of removal proceeds, the amount of light so given out will increase up to a point where the bright meteorites are relatively so numerous that their removal takes away more light than is added by the elimination of those which cast shadows on others in the field of view. Beyond this point the elimination of meteorites will act only to cause less light to reach us from the rings, which will consequently decrease continuously in brightness to the point of extinc-

tion. There is nothing about the problem to warrant the belief that there is a double maximum of light during the process of thinning out. Applying these considerations to the question in hand, it appears that if the meteor density is such in one zone of the crape ring as to give a maximum of light, or bead, as seen in projection, this light falling away as the denser middle ring is approached, we cannot expect a further increase in density, such as we find in the outer part of the middle ansa, to result in a second maximum, unless we assume entirely different plans of distribution of the meteorites in the two places. In fact it is difficult to see how any light can be transmitted through the denser portions of the ring, in view of the degree of opacity which we are bound to attribute to the rings as a result of Barnard's observation of the eclipse of *Japetus*.[1] This observation, it will be recalled, consisted in estimating the brightness of the satellite while it was undergoing eclipse by the rings. As the satellite passed through the shadow of the crape ring, its light gradually faded away, to become rapidly extinguished when it entered the thickening shadow of the middle ring. At the time of this observation (November 1, 1889) the sun was shining upon the plane of the rings from an angle of elevation of $11°10'$. The observation showed that the fainter parts of the middle ring are opaque for this angle of incidence, and it may reasonably be concluded that both the bright rings are equally so throughout their entire extent. The bright beads were visible on October 19, 1907, on which date the angle of elevation of the sun was $1°17'$. A ray of sunlight striking a particle on the dark surface would have to traverse a path within the medium composing the rings many times longer than that which was, or rather was not, traversed during Barnard's observation of the eclipse, the exact ratio being $\frac{\sin 11° 10'}{\sin 1° 17'}$, or 8.6. The absorption in the denser part of the middle ring would be correspondingly greater, and it would seem impossible that the amount of light seen in the outer beads could filter through such a region.

Bond sought to account for these phenomena on the basis of an opaque system, considering the outer beads to be the edges of the two bright rings seen through the Cassini division, and as the rings are

[1] *Monthly Notices*, **50**, 107, 1890.

practically opaque, it seems worth while to examine this suggestion somewhat critically. Bond's theory of the inner beads is weak, inasmuch as he assumes, for the purposes of his explanation, a division between the middle and crape rings, an assumption which is not tenable in view of Barnard's observation of the eclipse of *Japetus*. It is to be noted that, if his explanation of the outer knots is correct, a relation must be satisfied between the width of Cassini's division, the thickness of the ring system, and the position of the beads; or, to put it differently, if we assume the explanation to be the true one, we can form some idea of the thickness of the rings. The following rough computations were made before Professor Barnard's paper was published, and are based on Professor Aitken's measures published in *Lick Observatory Bulletin*, No. 127. In taking the mean of his results I have omitted the first observation of November 2, as it seems to have been affected by peculiar conditions. The means are as follows:

Date	1907, November 6.8
Distance of preceding outer knot from limb of planet	8″.376
Distance of following outer knot from limb of planet	8.145

These distances, reduced to the mean distance of *Saturn* from the sun, are respectively 7″.844 and 7″.628, or referring the positions of the knots to the center of the planet[1] we have

Distance of preceding knot from center of planet	16″.74	reduced to mean dist. of planet from sun.
Distance of following knot from center of planet	16.53	
Mean	16″.64	
Difference	0″.21	

Suppose the planet to be close to opposition. Let ⊙ represent the elevation of the sun on the south side of the plane and ⊕ that of the earth above the other, then (Fig. 1) if D be such a point that

$$ID\,(\tan\odot+\tan\oplus)=t\,, \tag{1}$$

where t is the thickness of the ring, the edge of the outer ansa will be visible partially at least between A and D, while that of the middle ansa will show between H and F, the line DF being directed toward the observer. If we could determine the position of the point D

[1] Barnard's measures of the system of *Saturn* (*Monthly Notices*, **56**, 171, 1896) have been used throughout this discussion.

we could compute t at once. The illumination at D and F is slight, as the illuminated parts of the exposed edges are points at these places. I have therefore assumed that the point D is twice as far to the right of the center of intensity of the bead as A is to the left. We have then:

Radius outer edge of Cassini's division	$17''.52$
Mean distance of knots	16.64
Probable distance out of inside edge of knots	14.88

Let

$$DCA=\theta^o \text{ and } ICA=\theta^i,$$

then

$$\cos\theta^o=\frac{14.88}{17.52}$$
$$\theta^o=31^\circ\ 50'.$$

Similarly

$$\theta^i=28^\circ\ 53'.$$

ID is therefore readily computed and equation (1) gives

$$t=0''.042\ ,$$

which corresponds to a thickness of slightly less than 180 miles.

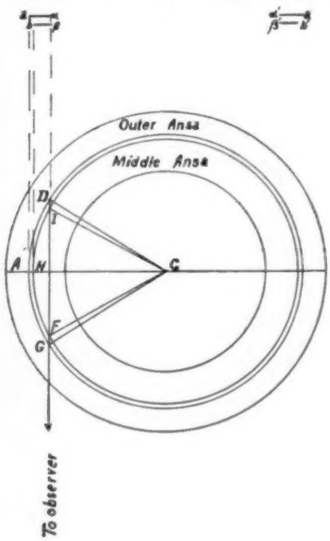


FIG. 1

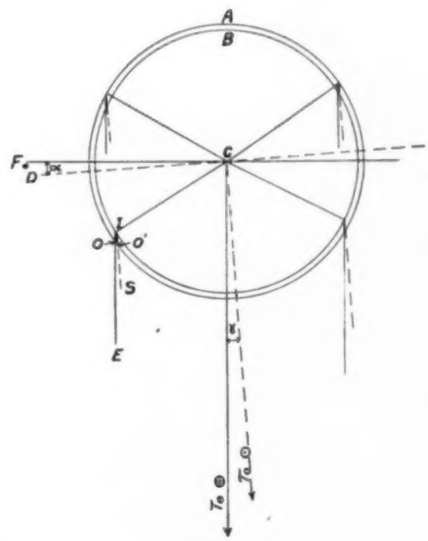


FIG. 2

For convenience let the bright edges AD and HF as seen in projection be represented by aa and $b\beta$ respectively, $a'a$ and $\beta'b$ being the corresponding edges on the outer side (Fig. 1, upper part). If,

as has been presumed, the planet is at opposition and the rings are of uniform thickness throughout, the points α, β, α' and β' are all equidistant from the center. Suppose now the sun to move to the right as indicated in Fig. 2. Under these conditions the symmetry of illumination is destroyed, with the result that the points α and α' (Fig. 1) will move to the left, while β and β' go to the right. To determine the amount of these motions, let I be the point on the periphery of ring B which corresponds to the new position of β. Let IE be drawn toward the earth and IS toward the sun. Designate by O and O' the points where these two lines cut the inner edge of ring A, draw CF through the center perpendicular to IE and CD perpendicular to IS. Further let

$$\alpha = FCD\,,$$ [1]

$$\begin{aligned} \phi^i &= ICF\,, \\ \phi^o &= OCF\,, \\ \Phi^i &= ICD\,, \\ \Phi^o &= O'CD\,, \\ \rho_1 &= CI\,, \\ \rho_2 &= CO\,. \end{aligned}$$

then

$$\begin{aligned} t &= IO' \tan \odot + IO \tan \oplus\,, \\ IO' &= \rho_2 \sin \Phi^o - \rho_1 \sin \Phi^i\,, \\ IO &= \rho_2 \sin \phi^o - \rho_1 \sin \phi^i\,, \\ \phi^i &= \Phi^i + \alpha\,, \end{aligned}$$

$$\frac{\cos \phi^o}{\cos \phi^i} = \frac{\rho_1}{\rho_2} = \frac{\cos \Phi^o}{\cos \Phi^i}\,.$$

These equations serve for the determination of $\phi^i = ICF$, the solution being effected by trial. The shift of β (Fig. 1) to the right, which we shall call δ_β, may then be readily obtained from the expression

$$\delta_\beta = \rho_2(\cos \phi^i - \cos \theta^i)\,.$$

The displacements of each of the points α, α', and β' may be obtained by a set of equations similiar in form to the above group. The values determined, using Barnard's constants of the system, are

$$\begin{aligned} \delta_\beta &= +0''.50\,, \\ \delta_\alpha &= -0.30\,, \\ \delta'_\beta &= +0.30\,, \\ \delta'_\alpha &= -0.51\,, \end{aligned}$$

[1] This is the angle between the earth and sun measured in the plane of the rings. The value for November 6.8, 1907, as determined graphically with sufficient accuracy for present purposes, is $3^\circ.95$.

where δ'_β and δ'_a are the displacements of β' and a' respectively. If the edges of the two rings were equally bright, we should expect the knots, due to the superposition of the bright lines on either side of the planet to maintain the symmetry of their positions with respect to the planet, but as the outer edge of ring B is much brighter than the inner edge of A the predominating motion in each knot must be toward the right from such a position. Further, the left-hand or following knot should be the brighter of the two. The amount of the dissymmetry introduced would be dependent on the relative brightness of the two edges, and also, to a great extent, on the relative thickness. In fact, if we suppose the bright outer edge of ansa B to be only slightly thicker than the inner edge of A, which is much the fainter of the two, the motion of the knots will be governed almost entirely by the motion of the points β and β'. The actual difference in the distances of the knots from the center, as observed by Aitken, is $0''.21$, the following knot being brighter and closer in.

It will be seen that the effect of the side illumination of the rings, as shown in Fig. 2, is to bring the beads closer together than they would be were the planet at opposition, and that this should have been allowed for in computing the thickness of the ring. Equation (1) by which t was computed is based on the supposition that the planet is at opposition, while the quantities which we substituted in it were obtained from measures made while the conditions indicated in Fig. 2 obtained. The value of t determined above should therefore be slightly increased, and may be put at about $0''.05$, a quantity which agrees better with Barnard's measures of the outer beads.

It may be remarked that a very good test of Bond's theory, as elaborated above, would be afforded by a complete set of measures of the knots, covering a larger range of values of the angle $(\odot + \oplus)$ taken without regard to sign. As this value increases, the knots should approach the planet, while if they are due to anything fixed on the rings their positions should remain constant. Barnard states that they have remained fixed throughout his observations, but it should be borne in mind that the quantities involved are small, and the observations to be determinative should be considered with reference to the angle $(\odot + \oplus)$. Barnard's measures put the knots $0''.20$

closer in than do those of Aitken, and the difference may be due to some such cause.

The foregoing comments are made, not in the belief that Bond's theory of the outer knots has by any means been proved, but merely to call attention to the fact that it accounts in a fairly satisfactory way for the phenomena observed, and may possibly furnish an independent means of determining the thickness of the ring system.

In closing I may be permitted to suggest the necessity of considering many of the phenomena presented by *Saturn's* rings in connection with the relative positions of the earth, the sun, and the plane of the rings. It may readily be shown, for instance, that an extensive body of meteoric stones, most of which are large enough to cast shadows, may appear much brighter when exactly at opposition than when viewed from slightly to one side of the path of incident light, the increase being dependent, to a certain extent, on the density of the swarm. It would therefore be of interest to learn whether any variation in the relative intensities of different parts of the ring system occurs when the planet approaches a point directly opposite the sun. For the exact realization of such a condition opposition must, of course, occur when the planet is at the node, though an opposition close to that position would doubtless suffice for the observation. It might also be worth while to note whether the crape ring is intrinsically brighter when the rings are narrow than when they open out, care being taken to allow for very obvious physiological effects tending to influence such an observation. In this connection the fact may be significant that the crape ring was independently discovered by three observers just as the system was opening out. It is not impossible that the increased amount of material which we must look through when the rings are narrow would cause what is ordinarily the outer zone of the crape ring to appear to be the inner one of the middle ring; in other words, the inner diameter of the middle ring may vary with the inclination of the rings to the line of sight. The writer is led to make these suggestions in view of the numerous changes reported in the appearance of the rings by many observers.

Dr. Barnard makes the suggestion that the rings are self-luminous, but dismisses it with the statement that such a theory is not in keeping with the physical constitution of the rings. While this explanation is

perhaps not the most probable one, still it does not appear as though it should be thus summarily disproved of. It is not unlikely that there is, in the aggregate, a great amount of friction, collision, etc., between the bodies composing the system, and the heat thus generated might be sufficient to cause the feeble luminosity observed, both over the surfaces of the two dense rings, and in the knots.

MT. HAMILTON
March 1908

ORBIT OF THE SPECTROSCOPIC BINARY OF *13 CETI*

By PHILIP FOX

The observing programme of the Bruce Spectrograph, prepared several years ago by Mr. Frost, includes a list of visual binaries, the observation of which might be of especial interest, and in certain cases would lead to a determination of the parallax. In some instances one component has been further resolved into a spectroscopic binary. Such a system is *13 Ceti* ($\alpha = 0^h\,30^m$, $\delta = -4°\,9'$, magnitudes $= 5.5$ and 6.2), of which the brighter component was found by Mr. Frost[1] to have a variable radial velocity with an approximate period of two days.

The parallax may be determined spectroscopically only where the *relative* velocity of the visual components is determinable, unless the absolute orbits of the components are known, as in the case of *Sirius*. Either the angular distance between them must be such that they can be observed separately with the spectrograph;[2] or, if closer, they must be of nearly equal brightness and must have such high relative velocity that the lines of the superimposed spectra are separated. For the problem of parallax determination the introduction of a spectroscopic binary into the system has both advantages and disadvantages. The orbit of the spectroscopic binary must be determined in order to get the velocity of the center of mass of this double component of the visual system. In a close pair, in case the spectra of both components of the spectroscopic binary are visible they may between them conceal the spectrum of the visual companion; but if only one spectroscopic component is visible then there might be a periodic[3] unmasking of the lines of the visual companion. These might otherwise, on account of low relative velocity, never be seen, or it might be necessary to wait until the relative radial velocity attains a maximum, which would occur when the visual companions cross the line of nodes on the passage nearest periastron.

The components of *13 Ceti* are always much too close to permit

[1] *Astrophysical Journal*, **25**, 60, 1907.

[2] The limiting distance for the Yerkes Observatory equipment is between 2″ and 3″.

[3] The interval would be the period or semi-period of the spectroscopic binary.

the spectrograph to attack them separately. Although only one component of the spectroscopic binary records its spectrum and the case is thus favorable for periodically revealing the spectrum of the visual companion, it is not visible on the spectrograms, which, therefore, do not furnish material for a determination of the parallax.

If we view the system from another standpoint, considering not the effect the resolution of one component of the visual system into a spectroscopic binary has upon the parallax problem, but the effect that a third body at a varying distance has upon the elements of the orbit of the spectroscopic binary, we encounter problems of even greater interest. It is fortunate for the consideration of these problems that several of the visual binaries with double components are among those of short period. Of about a dozen whose periods are known to be less than thirty years, *13 Ceti*, *κ Pegasi*, *ε Hydrae*, and perhaps *85 Pegasi*, have already been found to have as one of their visual components a spectroscopic binary.

The spectrum of *13 Ceti* is of the solar type and well suitable for measurement, particularly with the Hartmann spectrocomparator, the instrument used in this investigation. Preliminary to the measurement certain solar spectra, to serve as fundamentals, were photographed by Mr. Barrett. From these spectrograms, I chose one on a lantern-slide plate, which, though lacking in contrast, seemed most suitable otherwise. The iron and titanium spark supplied the comparison spectra, as with most of the spectrograms made here. After examining the plates carefully, I divided the spectrum into nineteen regions which more or less overlap. The data for the fundamental spectra were arranged in about the form which Hartmann uses.[1] The conversion factor, "*s*," is given for each region, together with wave-length of its center. For the reduction of the measures by the short method, using the formula

$$M_2 = \frac{\frac{1}{2}(\Sigma d_1 + \Sigma d_2)}{\Sigma \frac{1}{s}},$$

I have tabulated log $\Sigma \frac{1}{s}$ for various limiting regions employed in the measurement.

[1] *Publicationen des astrophysikalischen Observatoriums zu Potsdam*, Nr. 53, p. 31.

FUNDAMENTAL SPECTRUM

SUN, APRIL 12, 1907

$W=27.4$ $V_o=0.50$ km

Region	λ	s	Region	λ	s	Region	λ	s
1.....	4020	683	8.....	4235	822	15.....	4490	997
2.....	4034	693	9.....	4270	845	16.....	4524	1019
3.....	4062	710	10.....	4296	864	17.....	4546	1036
4.....	4112	742	11.....	4335	889	18.....	4596	1070
5.....	4138	759	12.....	4380	920	19.....	4641	1102
6.....	4168	780	13.....	4406	938			
7.....	4197	798	14.....	4452	970			

$\log \Sigma \frac{1}{s}$

Region	14	15	16	17	18	19
1..........	8.24022	8.26458	8.28717	8.30829	8.32779	8.34592
2..........	8.20202	8.22855	8.25305	8.27584	8.29682	8.31626
3..........	8.16077	8.18985	8.21656	8.24130	8.26397	8.28490
4..........	8.11631	8.14842	8.17771	8.20469	8.22930	8.25193
5..........	8.06900	8.10466	8.13694	8.16649	8.19329	8.21783
6..........	8.01720	8.05717	8.09304	8.12561	8.15497	8.18067
7..........	7.96009	8.00539	8.04560	8.08178	8.11414	8.14342
8..........	7.89592	7.94802	7.99361	8.03419	8.07015	8.10243
9..........	7.82295	7.88394	7.93636	7.98236	8.02268	8.05854
10..........	7.73791	7.81104	7.87239	7.92526	7.97095	8.01115

Two of the plates were two-prism spectrograms. The card of data for the fundamental spectrum has the same form as above.

Plate	Date (G.M.T.)	Exposure	Observer	v	n	v_c	O−C
	1906			km		km	km
IB 872	Oct. 1.787	75^m	B.	+11.93	17	+12.02	−0.09
912	Nov. 9.589	105	B.	+38.44	8	+37.53	+0.91
IIB 87	Nov. 23.544	184	F.-B.	−22.68	12	−20.72	−1.96
90	Nov. 24.553	210	F-.Fox	+39.03	12	+39.17	−0.14
IB 917	Nov. 27.514	101	F.-B.	−24.31	16	−25.11	+0.80
919	Dec. 1.542	92	F.-Fox	−19.57	17	−20.08	+0.51
921	Dec. 3.610	92	F.-Fox	−19.22	17	−19.20	−0.02
951	Jan. 25.531	90	B.	+30.44	14	+31.34	−0.90
	1907						
1164	Sept. 13.872	130	F.	+42.58	9	+43.19	−0.61
1170	Sept. 21.787	133	F.-B.	+16.93	15	+17.86	−0.93
1215	Oct. 20.696	120	F.	− 6.56	17	− 8.48	+1.92
1244	Nov. 23.592	100	Lee	+42.67	12	+42.18	+0.49
1249	Nov. 25.601	120	Lee	+39.62	9	+39.65	−0.03
1255	Nov. 27.610	82	Fox-B.	+33.14	13	+35.66	−2.52
1259	Nov. 30.604	120	Fox	− 2.85	17	+ 0.43	−3.28
1264	Dec. 4.571	180	Fox	+19.14	16	+18.99	+0.15
1273	Dec. 6.503	112	Fox-F.	+31.15	16	+30.98	+0.17
1277	Dec. 6.701	140	Fox	+14.21	13	+14.56	−0.35

The data for the eighteen spectrograms measured are given in the journal of observations. I need perhaps say that, because of the short period of the star, the dates were later corrected for the light-equation. In the column giving the observer, F = Frost and B = Barrett. Mr. Sullivan assisted in guiding for all of the plates. In column n are recorded the number of regions compared for each plate.

Using Schwarzschild's method I have found the following elements:

$$U = 2.0818 \text{ days}$$
$$\omega = 223^\circ.1$$
$$e = 0.062$$
$$\mu = 172^\circ.9276$$
$$T = J.D.\ 2417484.482$$
$$a \sin i = 981460 \text{ km}$$
$$K = 34.35 \text{ km}$$
$$V = 10.5 \text{ km.}$$

I give, for convenience of reference, Aitken's recently published[1] elements of the visual binary *13 Ceti:*

$$P = 7.42$$
$$T = 1905.28$$
$$e = 0.74$$
$$a = 0''.214$$
$$\omega = 51^\circ.75$$
$$\Omega = 50^\circ.40$$
$$i = \pm 48^\circ.05$$

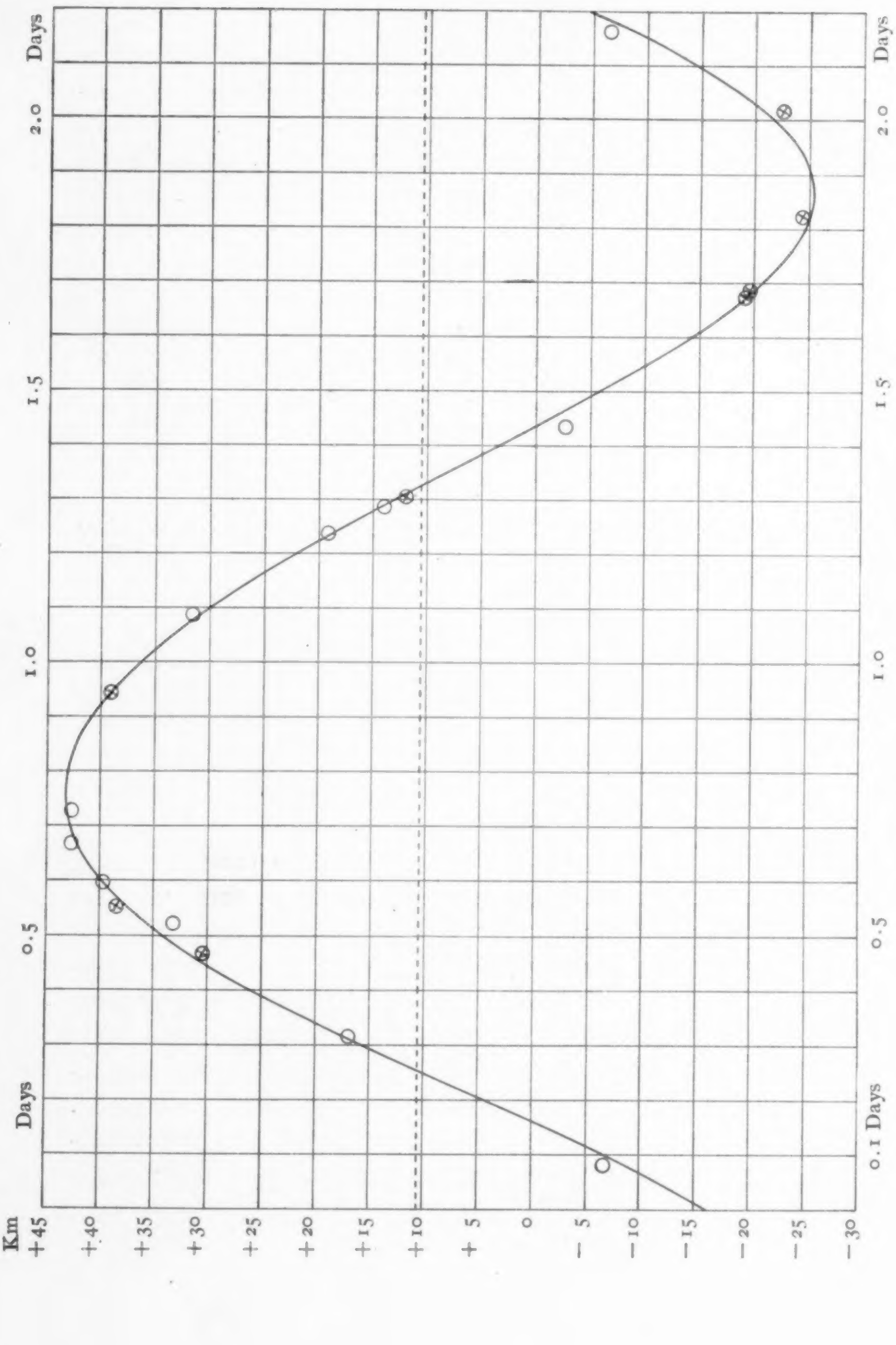
Angles increasing.

As the spectroscopic system is moving about the center of mass of the visual binary in an ellipse of great eccentricity, there may have been a sensible change in its velocity between the autumn of 1906 and of 1907. This change may have been large enough to affect considerably the elements given above. In the accompanying velocity-curve computed from the elements given above I have indicated the observations for 1906 with crossed circles. For neither year was the number of observations sufficient for a separate determination of the orbit.

When the parallax of the star is known, the relative radial velocities of the visual companions can be computed by the formula of Lehmann-Filhés.[2]

[1] *Lick Observatory Bulletin*, **110**, January 24, 1907.

[2] *A. N.*, No. 3332, **139**, 308, 1896.



VELOCITY-CURVE OF *13 Ceti* WITH OBSERVED POINTS

$$K=\frac{R}{864000 \sin \pi}\,\frac{a''}{p''}\,\frac{\mu \sin i(\cos u+e \cos \omega)}{\sqrt{1-e^2}}\,.$$

Assuming a parallax, $p''=0''.01$, the relative radial velocities for the two years are as follows:

Epoch	t	v	K	ΔK
1906.89	1.61 yr	152°.9	42.8 km	12.4 km
1907.85	2.57	167.1	30.4	

If the components are of equal mass we would need to displace the second set of observations up or down[1] on the velocity curve by 6.2 km. In view of the large proper motion of *13 Ceti,* given by Auwers as $0''.397$, the parallax is probably greater than $0''.01$. In the distribution of masses in the system the brighter component, the spectroscopic binary, probably takes the larger part. Presumably, then, the variation in the radial velocity, ΔK, of the spectroscopic system between these years is considerably less than 6.2 km and is probably insensible.

Of the various perturbations which the third body will produce on the spectroscopic binary some will probably be great enough to be appreciable. The period, U, should be noticeably longer at periastron than it is now, when near apastron. The great eccentricity of the visual orbit will be a powerful factor here. It may be possible to detect the revolution of the line of apsides, although this may be masked on account of the small eccentricity of the spectroscopic orbit. However, there may be a considerable change in the eccentricity. It will be essential for a study of the perturbations to secure plates at several epochs for separate determinations of the spectroscopic orbit.

I hope to secure enough plates in the autumn of 1908 to make a new determination of the orbit. The spectroscopic binary will then be at the apastron of the visual orbit, 1908.99, and the period will be at its minimum. The following year, at 1909.98, the motion will be parallel to the line of nodes and the observed velocity of the spectroscopic binary system will be the radial velocity of the visual system. In 1912.58 the spectroscopic binary will pass the node

[1] The sign is not yet determinable.

nearest periastron, whether ascending or descending is as yet unknown, and the visual components will have their maximum relative radial velocity. In 1912.70 it will be at periastron and will have its maximum period. In 1912.87 it will again be moving parallel to the line of nodes and the visual components will have zero relative radial velocity. In 1913.44 it will again cross the line of nodes. In moving the 180° between $\omega+v=0°$ and $\omega+v=180°$, accomplished in 0.86 year, the change in relative radial velocity of the components of the visual system is very rapid and plates for a determination of the orbit must be secured within an interval of a few days. It will eventually be possible to correct each observation for the motion of the spectroscopic binary system. It may be that to assure the necessary number of plates for a determination of the orbit at such a critical time as the periastron passage, the co-operation of other observers must be sought.

I wish in conclusion to acknowledge my indebtedness to Professor Frost for his advice and assistance in the investigation of this orbit.

YERKES OBSERVATORY
April 17, 1908

NOTE ON THE PHOTOGRAPHY OF VERY FAINT SPECTRA

By R. W. WOOD

It is a well-known fact that photographic plates require the action of a certain amount of light before any image can be developed, or rather that a plate can be exposed for some little time to a very dim light and still yield no image. It has been proposed on this account to fog plates slightly which are to be used for securing records of feebly illuminated objects, by a preliminary exposure to a very feeble light, but so far as I know the method is not generally used. Having recently used it with very great success, I think that it is worth bringing anew to the attention of those engaged upon the work of photographing weak spectra. In the work upon which I am now engaged, the photography of the resonance spectra of sodium vapor, excited by monochromatic radiations, with a large concave grating, exposures of twenty-four hours are necessary, and even then many of the lines are so faint as to be barely discernible on the plate. I am convinced that the action can be doubled, or the exposure time necessary to secure a given result cut in half, by a judicious use of the method.

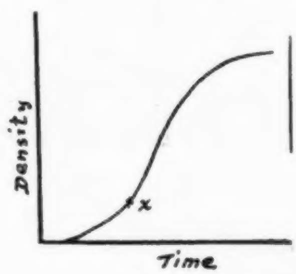


FIG. 1

As is well known, the curve representing the action of the light on the plate with the time is of the form shown in Fig. 1, the darkening of the plate being represented by the ordinates, and the times of exposure by abscissae. Preliminary exposure to feeble light carries the plate to the point where the curve begins to rise rapidly (x), and it is obvious that the exposure to the faint spectrum should be made to come on this part of the curve. It is first necessary to find out just what exposure is necessary to bring about this result. This can be done in a few minutes in the following way. A gas flame is turned down until the yellow tip is only three or four mm high, and a plate held at a certain distance from it, covered with a sheet of

black paper. The paper is now drawn aside step by step, exposing the plate in sections, the steps being made every two seconds. The plate is now developed, care being taken to push the development as far as possible.

Personally I favor glycin, and develop for fifteen or twenty minutes in a rather strong developer. By counting the number of strips which appear on the plate, it is possible to determine how long the exposure must be to secure a given action. I find that the best results are obtained by giving an exposure which will yield a faint image, say the time given for the recording of the second strip. A little experimenting is of course necessary before the best results are

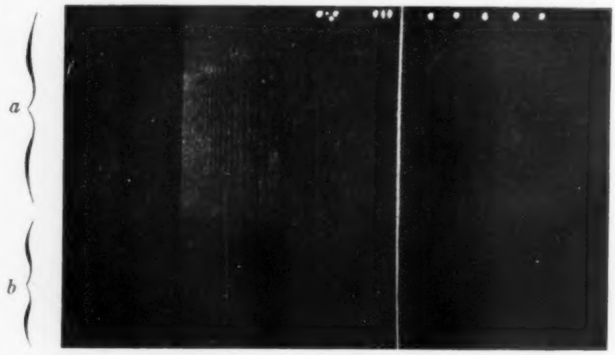


FIG. 2

secured. With a flame of the size described, this time is four seconds with the plate at a distance of about two meters. It is immaterial whether this exposure is made before or after the exposure of the plate to the spectrum.

I tested the method in the following way, and any experimenter can convince himself of the gain derived, by repeating the experiment. A nitrogen vacuum tube was placed in contact with the slit of a large three-prism spectrograph, great care being taken to secure an even illumination of the entire slit. The plate was exposed for five minutes, which was known to be far too short a time for securing a satisfactory record of the bands. After the exposure the plate was removed from the holder and the lower half covered with black paper. The upper half was then exposed to the small gas flame for

four seconds, and the plate developed to its utmost limit. The resulting picture is reproduced in Fig. 2, the portion "*a*" being the part which received the subsequent illumination. In the portion "*b*," which was screened, there appears only one strong line and a trace of the head of the band, while on the strip *a* the entire band appears, and in addition a number of lines to the right of the strong line, of which there is not the slightest trace in the lower portion of the picture. These lines I have marked with dots in case they fail to appear in the reproduction. The beneficial effect of the preliminary exposure of the plate to light can be well shown by exposing the plate under a screen which is moved laterally a few millimeters, say every two seconds. The plate is then turned through a right angle and the process repeated.

We may call one set of strips our "picture," the other set a series of progressively increasing fogging exposures, and we can determine in this way the effect of altering the duration of the "sensitizing light bath." It will be found that the number of strips which can be counted in the "picture" increases with the duration of the preliminary exposure up to a certain point, after which the action of the latter becomes rapidly detrimental. In the plate sent herewith[1] 8 strips can be counted on the unfogged portion and 15 on the correctly fogged part. As a result of these experiments I now treat all of my spectrum photographs in this way, and find that it reduces the time of exposure necessary by fully one-half. A very small electric lamp, operated by a storage cell, would be preferable to the gas flame.

JOHNS HOPKINS UNIVERSITY
March 1908

[1] Too faint for successful reproduction.—EDS.

ANNOUNCEMENT OF GENERAL INDEX TO VOLUMES I–XXV

A general index to the *Astrophysical Journal*, arranged both by authors and by subjects, covering Vols. I to XXV inclusive (January 1895 to June 1907), has been compiled by Mr. Storrs B. Barrett, librarian of the Yerkes Observatory. The material forms a volume of 136 pages conforming to the size and style of the *Journal* and is bound in paper. The execution of the plan, which was proposed more than a year ago, has been unavoidably delayed, but subscriptions filed in advance are now being filled and others desiring the book should order at once from The University of Chicago Press. The price is $1.50 postpaid. European subscriptions will be filled through Messrs. William Wesley & Son, 28 Essex Street, Strand, London, England, and future foreign orders should be sent to this address (price 6*s.* 6*d.*). Free copies cannot be supplied, either for periodicals received in exchange for the *Astrophysical Journal*, or otherwise.

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EDITED BY

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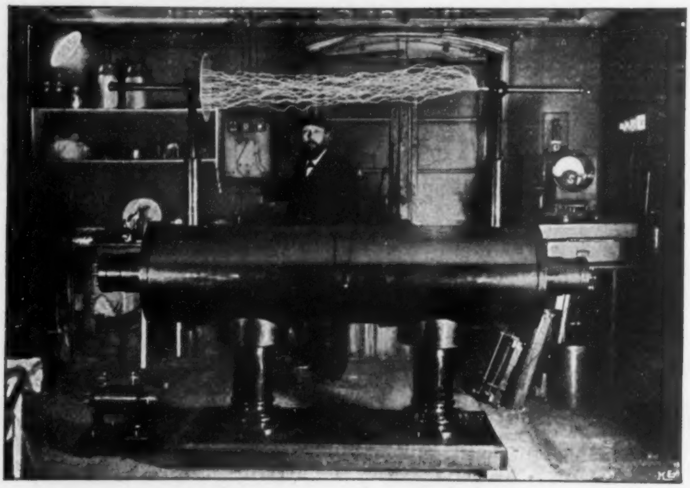

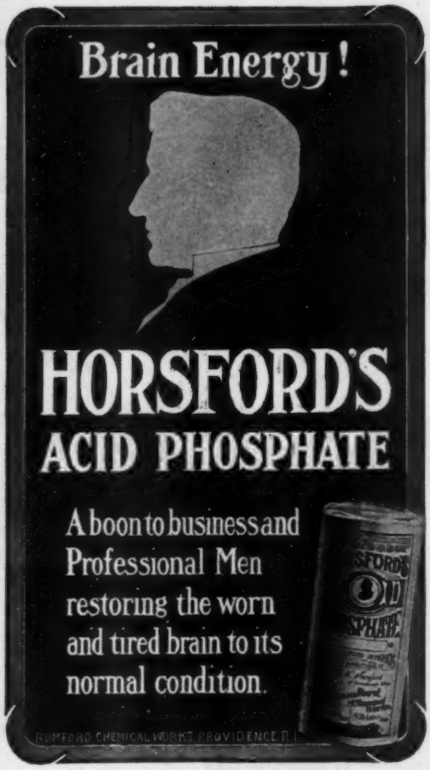
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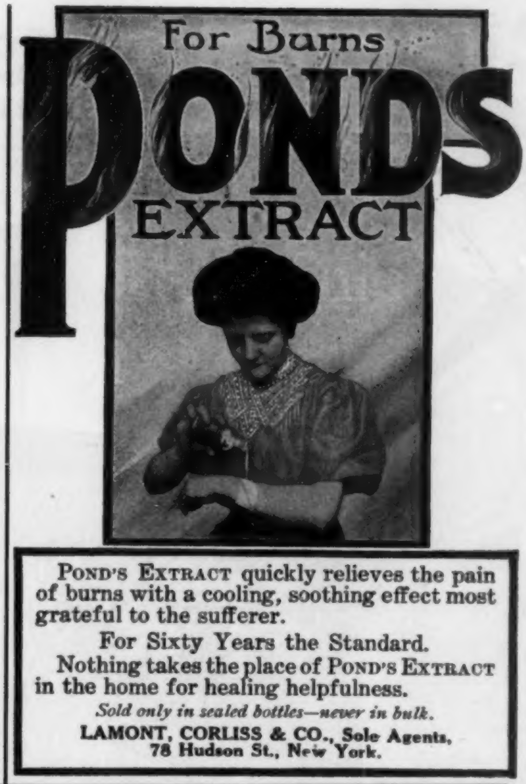
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